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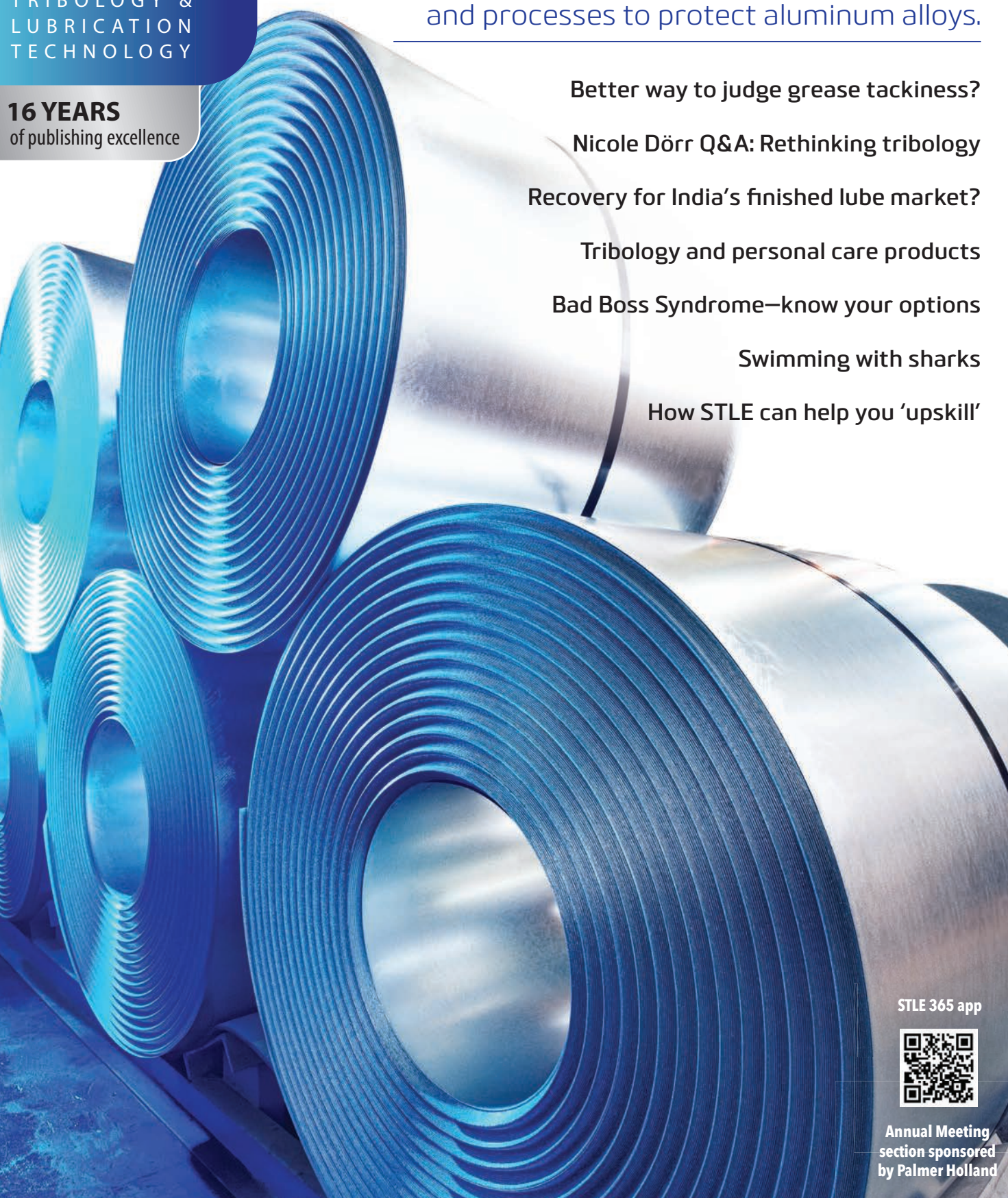

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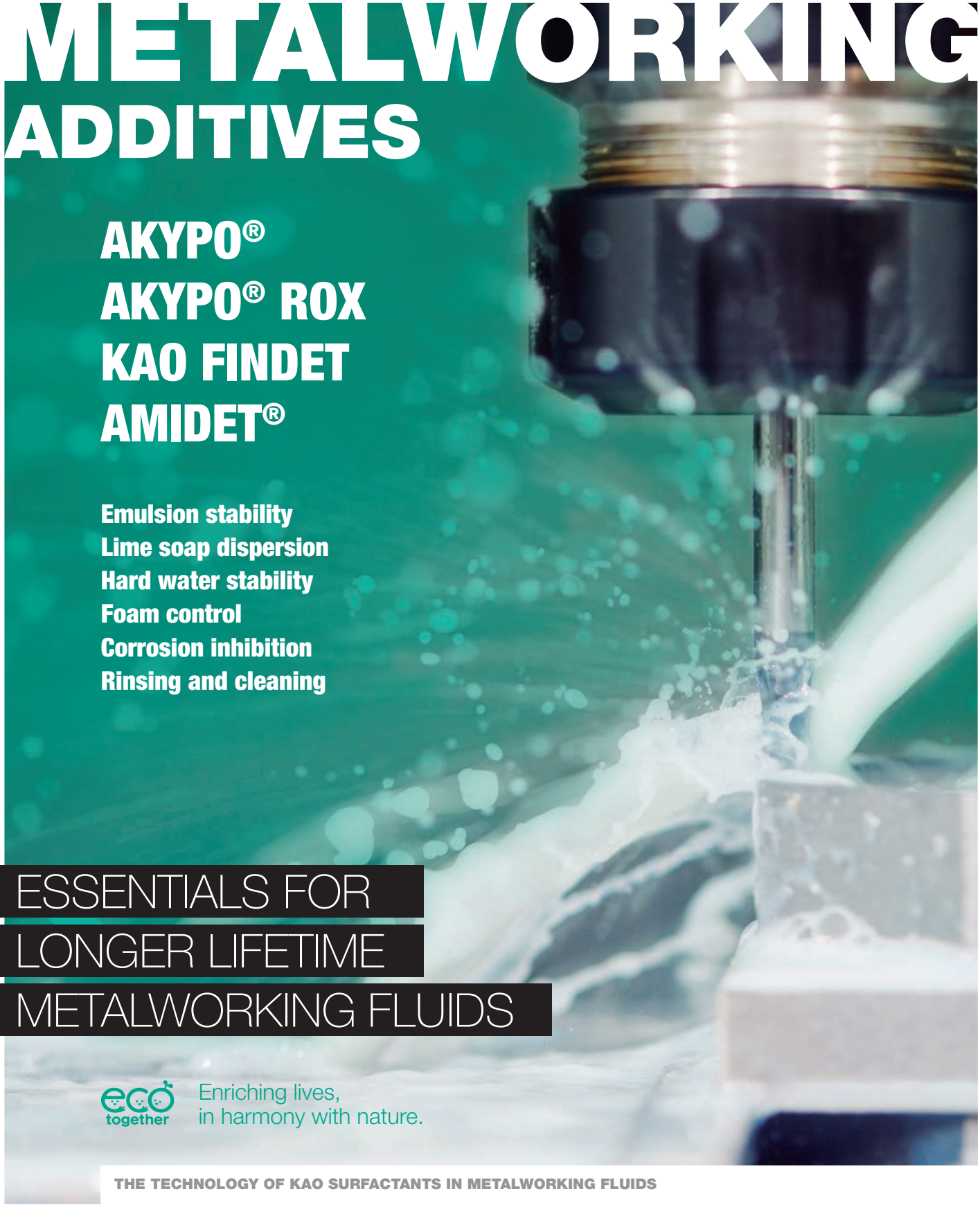

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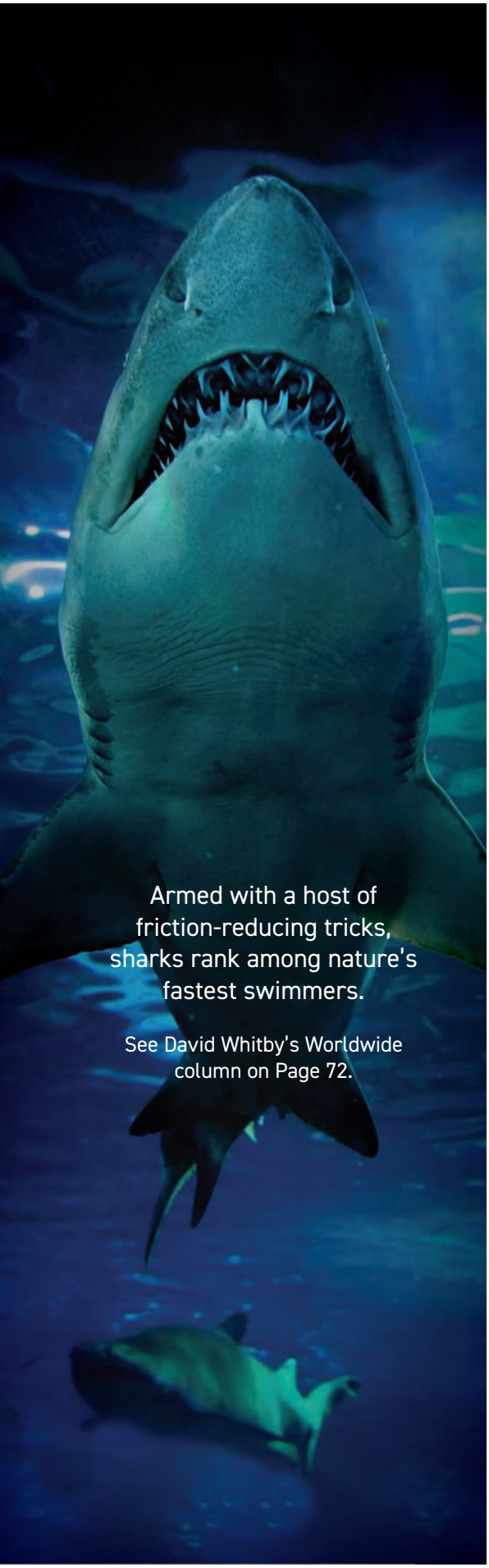

Armed with a host of friction-reducing tricks, sharks rank among nature's fastest swimmers.

See David Whitby's Worldwide column on Page 72.


# TRIBOLOGY & LUBRICATION TECHNOLOGY

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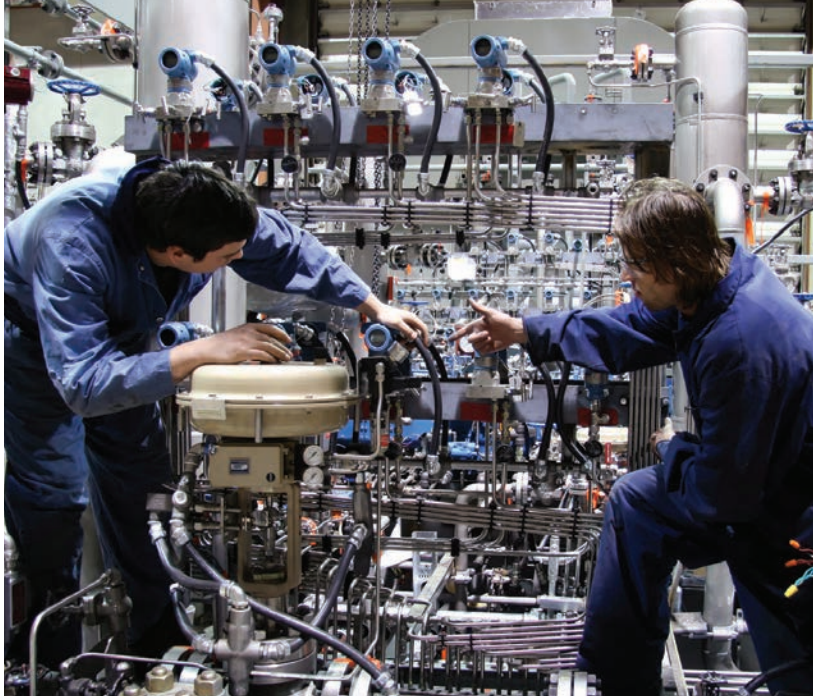
# Sustainability: Hard to predict the future

## *Managing and using resources efficiently will help improve quality of life.*



**Choosing a more sustainable approach to using lubricants is important for ourselves and future generations.**

**By Michael P. Duncan**

As of this writing, the final edits are being made to STLE's 2020 Report on Emerging Issues and Trends in Tribology and Lubrication Engineering, which is the third edition. This report, and the research effort behind it, encompass the global opinions and experiences of nearly 1,000 tribologists and lubrication engineers who participated in the research as advisors and editors. Thanks to all that have made this possible!

In addition, I just gave a presentation on the highlights of the latest Trends Report at the Technische Akademie Esslingen Conference (TAE) in Germany. I was one of the invited plenary speakers on the opening day of the conference held in January, which provided STLE exposure to the global European tribology and lubrication engineering community. The TAE Conference (22nd International Colloquium on Tribology) is a biennial meeting. It is an exchange forum for industry and academia to discuss tribological challenges for our community.

During the three-day conference, I was exposed to new environmentally responsible terms from a number of European companies: sustainability, zero waste, carbon neutrality, lifecycle carbon emissions, green wash, new clean power, green energy, etc. These terms were interspersed throughout the conference. The common theme is that we need to protect the environment, conserve resources and mitigate climate change because our planet's resources are finite, and our population continues to expand. Choosing a more sustainable approach to procuring, manufacturing, distributing, using and discarding lubricants (and other things we use and produce) will become more important for ourselves and future generations.

This environmental awareness is part of the EU's Sustainable Development Strategy. The overall aim of the EU Sustainable Development Strategy is to identify and develop actions to enable the EU to achieve a continuous long-term improvement of quality of life through the creation of sustainable communities able to manage and use resources efficiently, able to tap the ecological and social innovation potential of the economy, and, in the end, able to ensure prosperity, environmental protection and social cohesion.*

Other notable takeaways from the TAE Conference included varying viewpoints on the implementation of electric vehicles (EVs), hybrid vehicles (dual internal combustion engine-ICE and electric) and autonomous (self-driving) vehicles, wind power efficiency from the latest (very large turbine) windmills nearing equivalency to other forms of fossil-fuel power generation of electricity, biolubricants and biofuels. Not necessarily a sustainable approach to carbon neutrality, additive manufacturing (3D printing) R&D continues to open up new opportunities in manufacturing applications and fundamental tribology in EU academic institutions. For additional information on this and future TAE Conferences go to ***https://tinyurl.com/tae-de-ict.***

My final thoughts on the conference and the 2020 STLE Trends Report: EVs hold a promising potential for achieving EU's Sustainable Development Strategy if the electricity which is used to manufacture and power these vehicles is derived from renewable resources (wind, solar, hydro-electric). Even if we begin to replace ICE vehicles today with battery EVs, it will take 20-50 years before a significant impact on global warming can be achieved because of the current ICE vehicles in use today, the growing population, availability and cost of electricity, production of batteries, battery technology, electric vehicle parts and vehicle assembly facilities, governmental policy, consumer acceptance and additional wind and solar energy sources and storage. Bottom line—EVs will require new tribological solutions (drivetrain componentry, greases, gear oil additives, base stocks, lubricants and standards, surface coatings, battery technologies and effective thermal management solutions) from people like us!

Lastly, whether or not you believe in global climate change, the National Aeronautics and Space Administration (NASA) has an interesting graphic that you should look at. Click or Play the "Time Series: 1884 to 2019."** It is a very short timeframe in the life of our planet, but it is very interesting data, nonetheless.

*Mike Duncan is executive vice president of technology of Daubert Chemical Co. in Chicago. You can reach him at* ***mduncan@daubert.com****.*

*Available at ***https://ec.europa.eu/environment/sustainable-development/strategy/index_en.htm***.
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# Filter selection

## *Using the beta ratio in a practical way.*

**By Evan Zabawski**


During a lubrication audit of a manufacturing plant with injection molding machines it was noted that the OEM required the lubricant to be prefiltered to <5 µm—which was not being done. The predictive maintenance technician asked how much time prefiltration using suitable 3 µm filters would add to an oil change, and the answer depends on the desired cleanliness, which, in turn, depends on the beta ratio.

### 'What you lack in efficiency is made up in passes.'

Beta ratio is a singular value coupled with micron rating, e.g., $ß_3$=75, where 3 represents the micron rating and 75 represents the number of particles upstream of the filter where one particle would remain downstream of the filter after one pass through the filter; so why is it not written 75:1?

The method used to determine the beta ratio is laid out in ISO 16889:2008, known as the multi-pass method for evaluating the performance of a filter element. Essentially the test is comprised of a miniaturized oil circulation system with particle counters and pressure sensors installed both upstream and downstream of the filter. The fluid is then dosed with ISO medium test dust contaminant and circulated through the filter until terminal pressure is obtained.

The calculation uses the upstream particle count divided by the downstream particle count, then reduces the values so that the denominator is one, after factoring the number of passes. Therefore, the reported value of 75 (":1" is assumed) indicates an average of 74 out of 75 particles are removed per single pass through the filter being evaluated.

How some people try to make sense of the beta ratio is to convert it to single pass efficiency—a percentage removal rate. For a beta ratio of 75, the efficiency is 98.7%, obtained by taking 74 divided by 75, then multiplied by 100. The problem is that 98.7% sounds very high, yet a beta ratio 1000 is commonly available, and its efficiency is 99.9%, a seemingly small-sounding improvement.

The reality is that the 1.2% difference compounds with each pass through the filter and after just four passes a $ß_3$=75 filter would allow over 30,000 times as many particles through the filter compared to a $ß_3$=1000 filter. From this perspective, there appears to be a significant difference between the two filters, which is why single pass efficiency can be somewhat misleading.

Ultimately it is best to leave beta ratio alone, without conversion, and to simply calculate the number of passes required to obtain the desired cleanliness. This calculation is straightforward: take the existing particle count at the required micron size and divide by the beta ratio to obtain the resulting particle count after one pass. Divide this answer by the beta ratio again to obtain the particle count after two passes; repeat until desired cleanliness is reached.

For example, let's assume 1,000,000 particles larger than 3 µm is the current cleanliness of the fluid and calculate the resulting cleanliness from four passes. Taking 1,000,000 and dividing by 75, then that answer is divided by 75, and then two more iterations would yield 0.031605 particles. Repeating the calculation by dividing the particle count by 1,000 through four iterations yields 0.000001 particles.

Though it is true the former value is over 30,000 times higher than the latter, both filters would eventually reduce 1,000,000 particles to less than one particle. The practical perspective is that transferring oil from a drum using a duplex filter cart equipped with twin $ß_3$=1000 filters could reduce 1,000,000 particles to one particle in one pass, but twin $ß_3$=75 filters would require almost twice as many passes to achieve the same cleanliness.

In the end, I usually say, "What you lack in efficiency is made up in passes." Filters rated at the same micron value will eventually remove all the same particles, but the beta ratio determines how quickly.

*Evan Zabawski, CLS, is the senior technical advisor for TestOil in Calgary, Alberta, Canada. You can reach him at* ***ezabawski@testoil.com****.*

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# Upskilling: New word for STLE's core value

## *Technical changes and challenges demand lifelong learning.*

**By Edward P. Salek, CAE**
*Executive Director*

**The latest version of STLE's Emerging Trends Report, due in May, examines the electric vehicle market, a topic not even mentioned in the original 2014 release.**

There's a trendy way to describe an STLE member benefit that goes back to the organization's founding more than 75 years ago.

Upskilling is defined as the business of expanding your personal knowledge base beyond what was learned in a full-time university education program.

Thought-leaders in technology and business are stressing its importance. In a recent interview, John Hennessy, the former president of Stanford University who is now non-executive board chair of Alphabet (Google's parent company) explained the concept.

"At Stanford, many years ago we thought of part-time education as primarily focused on getting people master's degrees, he said. "Today, it's a certificate--three courses in machine learning, three courses in cybersecurity and block chain--that can allow people to upskill themselves broadly across the field."

Much like the people that Hennessy is describing, STLE members are already well-educated. Research shows that more than 40% have earned an advanced degree in science or engineering. However, the point of his comment is that the rapid and accelerating change in all technical fields demands ongoing education.

The latest edition of STLE's Emerging Trends and Issues Report, to be released in May, tracks many of the major new developments in tribology and lubrication. Key areas detailed include transportation, energy, manufacturing and medical/health application sectors.

How quickly are things changing? The first Trends Report, published in 2014, included no discussion of electric vehicles. In the 2020 Report, there is a heavy focus on the impact that the expected shift toward pure electric vehicles will have on the tribology and lubricants business and the people who work in it. Many other areas also are experiencing rapid market changes and different technology requirements.

Given these shifts, how does STLE support individuals and companies with the upskilling opportunities needed to keep pace? Here are three options.

- TLT magazine provides readers with a wealth of practical information every month. In addition, the TLT Archives found on the STLE website gives members access to prior issues dating back to 2009—that's more than 130 complete issues and 1,500 articles on literally every aspect of tribology and lubrication engineering.
- Learning Pathways is another website-based reference. This body of knowledge includes extensive peer-reviewed reference materials filtered by relevant key subject areas (additives, base oils, hydraulics, etc.) and then further divided into Basic, Intermediate, and Advanced competency levels for better use as a self-study or reference guide. Pathways also includes a glossary of terms that defines everything from absolute viscosity to ZDDP – as well as most other terms in between.
- The upcoming 2020 Annual Meeting and Exhibition in Chicago on May 3-7 offers 11 professional education courses as part of the technical program. These range from instruction on the fundamental concepts in lubricants and lubrication to others exploring newer technical horizons like nano-tribology. Meeting details and course descriptions are available on the STLE website at ***www.stle.org***.

Education remains at the center of STLE's Connect-Learn-Achieve value proposition. According to the most recent member needs study, 70% of respondents rated industry specific educational programs and resources as the number one reason for becoming a member. In the future, look to our organization for the technical skills needed to upskill and capitalize on opportunities presented by the changing technical landscape.

*You can reach Certified Association Executive Ed Salek at* ***esalek@stle.org****.*

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# Aqueous lithium-ion battery

**By Dr. Neil Canter**
*Contributing Editor*

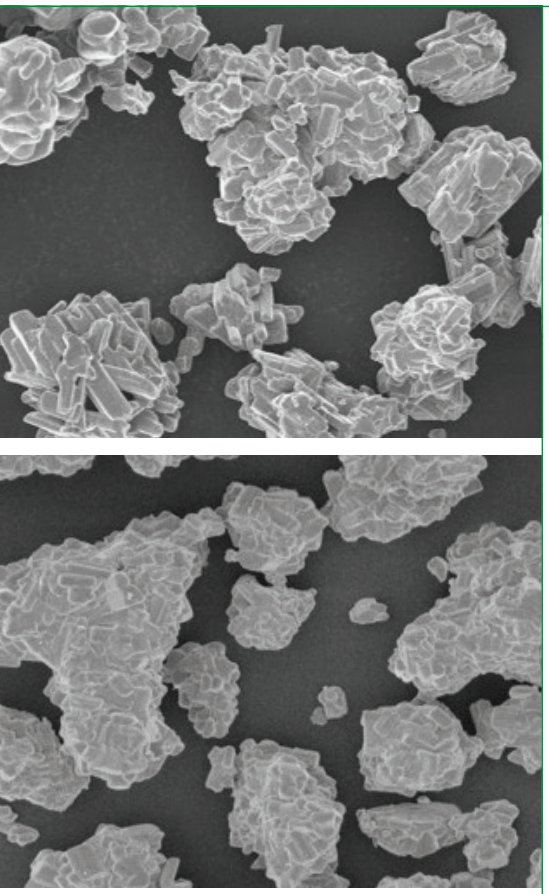

Figure 1. **Scanning electron microscopy images of the two niobium tungsten oxides evaluated for use as anodes in an aqueous lithium-ion battery.** *Figure courtesy of Rensselaer Polytechnic Institute.*

## KEY CONCEPTS

An aqueous lithium-ion battery was developed using niobium tungsten oxide as the anode and a water-in-salt electrolyte.

Niobium tungsten oxide was chosen as the anode because it has the potential to generate high volumetric energy densities and has well-defined channels to facilitate diffusion of lithium ions.

The volumetric performance observed was the best seen to date for an aqueous lithium-ion battery.

## The theoretical applied voltage limit was overcome in developing a safe lithium-ion battery.

**Ongoing development** of lithium-ion batteries is enabling researchers to steadily improve their performance and durability. A focus point has been to find approaches for improving the graphite anode. But work has also been underway to find alternative materials for the cathode.

In a previous TLT article[1], researchers identified vanadium disulfide as a potential cathodic material. This material was chosen because it is electrically conductive and has two important benefits (lighter in weight and environmentally safe) as compared to the incumbent cathode, lithium cobalt oxide. Inherent instability in the vanadium disulfide cathode was overcome through application of a thin layer of titanium disulfide.

Safety issues continue to be a significant hurdle for lithium-ion batteries. Nikhil Koratkar, professor of mechanical, aerospace and nuclear engineering at Rensselaer Polytechnic Institute in Troy, N.Y., says, "The existing lithium-ion battery requires the use of a non-aqueous, organic solvent-based electrolyte. This material is the source for concerns about flammability, moisture sensitivity and toxicity. Fabrication of the battery is more expensive because safeguards must be put in place when using a solvent-based electrolyte"

An option to examine is replacement with an alternative that is compatible with water. Koratkar says, "The problem with using an aqueous electrolyte is that the theoretical applied voltage is limited to less than 1.23 volts. Above that limit, water will electrolyze to form hydrogen and oxygen. In actuality, voltages between 1.6 and 1.8 volts can be achieved without water decomposition."

Recent work by another research group has provided an aqueous electrolyte composition that is resistant to electrolysis and enables the resulting battery to exhibit a high energy density. Koratkar says, "This composition, known as a water-in-salt electrolyte, is readily water soluble and forms a gel that contains a high concentration of salt with a limited amount of water."

Among lithium-containing salts, only lithium bis (trifluoromethane sulfonyl) imide has a high enough solubility in water to be used for the water-in-salt electrolyte.

In theory, an aqueous lithium-ion battery should exhibit superior rate performance because aqueous electrolytes have higher ionic conductivity than organic solvents. But in actuality this has not been the case.

Koratkar believes that one of the challenges is to optimize the anode and the cathode used with the aqueous electrolyte. He says, "A cathode based on lithium manganese oxide is effective, but finding a suitable anode has been challenging. Graphite is not suitable for use as an anode because this material is hydrophobic and not compatible with aqueous systems."

A new anode has been identified and evaluated in an aqueous lithium-ion battery.

### Niobium tungsten oxide

Koratkar says he and his colleagues evaluated niobium tungsten oxides as a potential anode candidate for two reasons: "Being oxides, these materials hydrogen bond with water and hence exhibit good hydrophilicity. They also exhibit well-defined channels which facilitate the diffusion of lithium ions leading to fast charging."

The niobium tungsten oxides do contain two heavy elements (niobium and tungsten), but these materials are very densely packed, leading to the ability of the researchers to produce a very dense anode electrode. This means that niobium tungsten oxides have the potential for generating high volumetric energy densities.

Particles between 20 and 30 microns in size were used by the researchers and are shown in Figure 1.

The researchers evaluated two niobium tungsten oxides that have the following structures: $Nb_{18}W_{16}O_{93}$ and $Nb_{16}W_5O_{55}$. Both species were evaluated in a full-cell aqueous lithium-ion battery by cyclic voltammetry using the lithium-based water-in-salt electrolyte and a lithium manganese oxide-based cathode.

## Safety issues remain a significant hurdle for lithium-ion batteries.

Koratkar says, "We focused on evaluating the volumetric energy density as opposed to the gravimetric energy density which has been more widely used in academia. But for consumer electronics, electric vehicles and grid storage industries, volumetric energy density is more relevant. The high density of niobium tungsten oxides means that the anode stores a large amount of energy in a small volume."

In evaluating the two niobium tungsten oxides, the researchers determined that the species with eighteen niobium and sixteen tungsten atoms exhibited better performance in the aqueous electrolyte. Koratkar says, "$Nb_{18}W_{16}O_{93}$ is more effective than $Nb_{16}W_5O_{55}$ because it contains a greater number of tungsten ions per formula unit. Under the restrictive voltage window for the aqueous electrolyte, tungsten is more dominant in the reduction reaction than niobium."

For a traditional non-aqueous electrolyte containing battery, the opposite takes place. Koratkar says, "The oxide with a higher percentage of niobium performs better because this atom can more effectively undergo reduction at the higher voltage possible in the non-aqueous battery."

The researchers found that the more effective niobium tungsten oxide exhibited a volumetric rate of approximately 200 ampere hours/liter at a 1C rate which is higher than graphite. Battery cycling could also be conducted at a higher rate with only a 25% reduction in capacity detected.

The volumetric performance observed by the researchers was the best seen to date for an aqueous lithium-ion battery. For the future, the researchers will be trying to extend the electrochemical stability voltage window so the aqueous lithium-ion battery can compete more effectively with non-aqueous batteries.

Koratkar says, "We will be trying to optimize the electrolyte which is currently being used at a concentration of 21M. Moving to a higher concentration may reduce the amount of water in the electrolyte increasing the voltage window but also increasing cost. Evaluating lower electrolyte concentrations will also be tried to see how the voltage window is affected with a higher concentration of water."

Koratkar also indicates that other electrolytes will be evaluated. He adds, "The anode will be optimized by replacing niobium and tungsten with lighter weight elements in the form of other oxides or through doping."

Additional information on this research can be found in a recent article[2] or by contacting Koratkar at ***koratn@rpi.edu***.

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# Ionic liquid-based additives for automotive lubricants

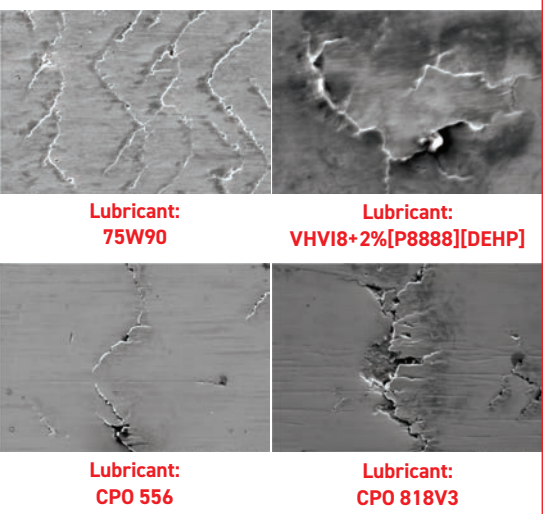


Figure 2. **Extensive micropitting is shown in the top left image of the roller surface topography for carburized AISI 8620 steel used in testing of a 75W-90 commercial rear axle lubricant. The other three images of the same surface show much less surface cracking when rear axle lubricants formulated with ionic liquids were evaluated in the same test.** *Figure courtesy of Oak Ridge National Laboratory and Driven Racing Oil.*

## KEY CONCEPTS

Ionic liquids based on phosphonium cation derivatives and either phosphate or phosphinate anions were evaluated in rear axle lubricants and low viscosity engine oils.

The presence of the ionic liquids in the axle lubricants led to significantly reduced surface cracking.

A synergism between the ionic liquid and a secondary ZDDP in fully formulated SAE 0W-12 engine oils led to reduced wear, a low boundary coefficient of friction and a 9.9% improvement in fuel economy versus a commercial SAE 5W-30 engine oil.

## Phosphorus-based ionic liquids show potential as additives in rear axle lubricants and engine oils.

**In the effort to improve** the efficiency of high-performance lubricants used in racing, researchers are examining a wide range of additives that can be used to supplement the performance of automotive lubricants. One material that has been actively examined is graphene and its derivatives.

In a previous TLT article[1], graphene balls were crumpled through a sonication process and then dispersed in 4 cSt polyalphaolefin (PAO) at a treat rate of 0.1% by weight. Testing done with a pin-on-disk tribometer showed lower coefficient of friction and wear rates compared to graphite platelets. However, graphene is still a solid, so solubility can be problematic.

Another additive type that has been evaluated in lubricants is ionic liquids. STLE-member Lake Speed, general manager of Driven Racing Oil in Olive Branch, Miss., says, "Ionic liquids are salts that exhibit melting points below 100 C. There are many possible ionic liquids that can be produced from anions and cations."

Ionic liquids are polar species which can be difficult to incorporate in lubricants because of their potential incompatibility with nonpolar base oils. Speed worked with STLE-member Dr. Jun Qu and other researchers from Oak Ridge National Laboratory who had developed phosphorus-based ionic liquids to determine how their use may improve the performance of pinion gears used in rear axles and in low viscosity (SAE 0W-12) engine oils. The ionic liquid developed by ORNL demonstrated excellent compatibility and solubility in traditional motor oil and gear oil base stocks.

### Pinion gears

The ionic liquids under evaluation are based on phosphonium cation derivatives and either phosphate or phosphinate anions. An example is tetraoctylphosphonium bis (2-ethylhexyl) phosphate which is designated as [P8888] [DEHP].

Speed says, "We evaluated the performance of ionic liquids in rear axle lubricants used in pinion gears. The reason is that the highest load and smallest contact area in the rear axle are observed with pinion gears. This is an application where lubricants are subjected to really high pressure. As a result, lubricants must be formulated with extreme pressure additives to maintain performance under such severe operating conditions."

From a lubricant standpoint, the problem is that conventional axle lubricants are formulated with sulfurized additives that can promote micropitting. Speed says, "Sulfurized additives can attack the grain structure in the pinion gear leading to micropitting and cracking."

Further challenging the researchers is the move by the automotive industry to reduce the viscosity of rear axle lubricants from SAE 75W-140 to SAE 75W-90 which could lead to increased surface damage (due to rolling contact fatigue) and sliding wear. The benefit of this viscosity reduction is a 1.4% improvement in efficiency.

Speed and his colleagues investigated the performance of two of the phosphorus-based ionic liquids as additives in fully formulated axle lubricants. Traction coefficient and wear results showed that several low-viscosity axle lubricants formulated with the ionic liquids exhibited comparable friction and wear to commercial 75W-90 and 75W-110 gear oils.

The researchers used scanning electron microscopy to examine the micropitting seen on the metal surface after testing. Figure 2 shows the roller surface topography for carburized AISI 8620 steel used in evaluation testing. For this particular test, the gears were subjected to a slide to roll ratio of 30%. The image of the 75W-90 commercial oil shows extensive micropitting while the three other images for axle lubricants containing the ionic liquids exhibit significantly reduced surface cracking.

**Low-viscosity engine oils**

The researchers also evaluated the ionic liquid additives in fully formulated SAE 0W-12 engine oils. Due to the phosphorus-based nature of the ionic liquids, the researchers decided to evaluate them in combination with a secondary zinc dialkyldithiophosphate (ZDDP).

**The ionic liquids evaluated contained phosphorus-based anions and cations.**

Speed says, "We found that a 1:1 ratio of the ionic liquid with the ZDDP led to superior results including a 50%-80% reduction in wear and a very low boundary coefficient of friction (0.03-0.04). Cam lobe wear was also reduced by 40%, and the engine oil displayed a 9.9% improvement in fuel economy versus a commercial SAE 5W-30 engine oil."

The optimum treat rate for the ionic liquid and the ZDDP was found to be 400 ppm each. Speed says, "We looked at other ratios but did not see the same synergy."

The researchers found that the surface concentration of phosphorus, sulfur and oxygen in engine oils with both the ionic liquid and ZDDP are 30 to 70 time higher than those in the bulk oil. This result may help to explain in part the synergism seen between the ionic liquid and ZDDP.

An interesting phenomenon noted by the researchers was that extended friction testing using the Plint Reciprocating Rig resulted in an increase in friction and higher wear due to the micropitting after 10 kilometers of sliding at elevated temperatures. This result occurred in all engine oils tested including commercial lubricants containing no ionic liquid. Speed says, "We believe that running at a temperature of 100 C with pure sliding produced a unique tribofilm leading to micropitting. ZDDP and the friction modifier appear to be the major contributors to the micropitting. Because engines operate in a dynamic environment of both sliding and rolling, we were not overly concerned by the findings. However, we did develop a formula that greatly reduced the micropitting."

With the movement to lower viscosity-based lubricants in an effort to improve efficiency, this work shows the potential for using ionic liquids as additives to improve the performance of automotive lubricants and minimize concerns such as micropitting and wear.

Additional information can be found in presentations given at the 2019 STLE Annual Meeting[2] and at the 2019 SAE World Congress[3]. Details on the composition of the ionic liquids can be found in US Patent 9,957,460 published in 2018.[4] Driven Racing Oil can also be contacted at ***Tech@DrivenRacingOil.com***.

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# Using AI to identify battery electrolytes

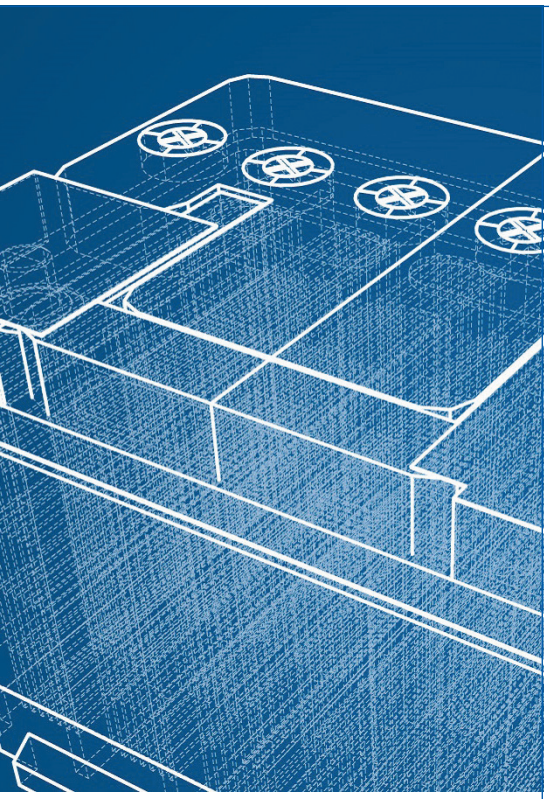

Figure 3. **In an effort to facilitate the identification of more effective and stable battery electrolytes, research has been conducted to identify candidates through the use of machine learning and artificial intelligence.** *Figure courtesy of Argonne National Laboratory.*

**KEY CONCEPTS**

Instability is the current types of batteries under development has been traced to the organic electrolytes used.

Identification of more stable electrolyte candidates was accomplished by evaluating the enthalpy of formation for 133,000 organic molecules in a specific database.

High-performance computing and AI were used to identify specific candidates.

## Enthalpy of formation was determined to assess molecular stability.

**Extensive research** is ongoing to develop a commercially viable battery that is a cost-effective alternative in automobiles to the internal combustion engine. The leading candidate continues to be lithium-ion batteries.

But lithium-ion batteries face safety issues that are caused by instability traced to the organic electrolytes used which can facilitate the formation of dendrites. If left unchecked, dendrites can grow between the anode and cathode, leading to short circuiting of the battery which can cause overheating and eventually a fire. In a previous TLT article[1], researchers discussed the development of a solid electrolyte based on aramid nanofibers and poly (ethylene oxide) that appears to stop the growth of dendrites.

As an approach to better understand how lithium-ion batteries function and to expedite their development, researchers have turned to artificial intelligence (AI). A previous TLT article[2] reported on a study to predict the life of lithium-ion batteries using AI. Researchers initially established a data set based on results from 124 commercial fast-charging batteries that underwent varying charge/discharge cycles. Ultimately, the researchers compiled a data set with approximately 96,7000 cycles that predicts the operating life of specific lithium-ion batteries. Of the models used, the most accurate one to predict battery life focused on changes in voltage as a function of the number of cycles.

Dr. Rajeev Assary, chemist at the U.S. Department of Energy's Argonne National Laboratory in Argonne, Ill., says, "Organic molecules are contained within the electrolyte of a lithium-ion battery or the next-generation redox flow batteries. Three parameters that must be used to evaluate their performance include oxidation-reduction (redox) window, solubility and stability. The latter is very important as it will directly determine the operating lifetime of the battery."

In evaluating electrolytes, Assary indicated that predicting molecular stability is very important. To accomplish this task, thermodynamics is a useful tool. Assary says, "Evaluating accurate enthalpy of formation values is essential to screen large chemical space including the measure of molecular stability. This parameter is a measure of the enthalpy change that occurs when a molecule decomposes to its pure elements."

Assary and his colleagues have now determined the enthalpy of formation for 133,000 small organic molecules that contains the molecular fingerprints of the battery electrolyte candidates using High Performance Computing and AI (see Figure 3).

### GDB-9 database

The researchers initially examined a database known as GDB-17. Assary says, "We wanted to work with the GDB-17 database because it contained a total of 166 billion organic molecules and would have given us insight into a large number of options. GDB-17 contains all molecules of up to 17 heavy atoms of the first row of the periodic table (including carbon, nitrogen, oxygen and fluorine) and hydrogens. Unfortunately, there is insufficient computing power to utilize GDB-17."

Instead, the researchers evaluated a subset of 133,000 organic molecules that comprise GDB-9 where the number of first row atoms is reduced to nine. Assary says, "In our work, we used molecules that contained carbon, nitrogen, oxygen, sulfur and some but not too many halogens."

The researchers used a computationally intensive and accurate model known as G4MP2 to assist with calculating the enthalpy of formation. Assary says, "G4MP2 is based on a classic theory that evaluates all electronic interactions. It provides an accurate analysis of the energies of the organic molecules in GDB-9."

**Researchers used a subset of a database that contained 133,000 organic molecules.**

At the same time, the researchers used a less accurate ccomputationally-based modeling framework that is derived from density functional theory, which is a quantum mechanical modeling framework that calculates the electronic structure of in large systems. The objective was to provide a basis for the machine learning model.

To facilitate the process, the researchers selected 459 organic molecules that have known enthalpies of formation to use in the machine-learning process. Assary says, "We obtained good correlation (less than 1 kcal per mole) between the experimentally determined and G4MP2 determined enthalpies of formation for these molecules."

The researchers also used G4MP2 and a less accurate density functional theory method known as B3LYP to evaluate the enthalpies of formation for a small set of 66 organic molecules containing between 10 and 14 heavy atoms. Assary says, "We compared experimental values with computational values and also found good correlation that was within 1-2 kcal per mole."

The next objective for the researchers is to use G4MP2 and density functional theory to evaluate molecules with charges. Assary says, "We have initially worked with neutral molecules, but charged molecules and fragments are present in battery electrolytes, and this must be considered in selecting the proper one. Empirical electrochemical techniques such as cyclic voltammetry will be used to compare values obtained through machine learning."

The researchers hope to predict at what voltage a specific molecule will oxidize or reduce. Assary says, "We also intent to use solubility as a criterion to identify electrolyte candidates."

Additional information can be found in two recent articles[3,4] or by contacting Assary at ***assary@anl.gov.***

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*Neil Canter heads his own consulting company, Chemical Solutions, in Willow Grove, Pa. Ideas for Tech Beat can be submitted to him at* ***neilcanter@comcast.net.***

# Recovery for India's finished lubricant market?

*After recent setbacks, and buoyed by gains on the consumer side, modest growth is expected for the next five years.*

**By Anuj Kumar Singh and Hareesh Nalam**

**India's automobile production contracted 10%-12% in 2019, with the most severe shrinkage in commercial vehicles.**

**The finished lubricant market** growth story in India has fascinated many by its continued resilience amidst difficult times. During the last decade, when the global economy was reeling, India was one of the few markets not greatly impacted. Several factors helped India emerge unscathed from that crisis, including strong economic fundamentals, a growing middle class and increasing demand from the domestic market (which hedged it from shocks in export markets).

What followed was a period of consistently high growth. Naturally, the finished lubricant market benefitted from it and made India one of the fastest major lubricant-consuming markets in the world. Kline estimates that Indian finished lubricant demand has grown at a CAGR of around 1.8%-2.0% during the period between 2013 and 2019.

## Signs of weakness

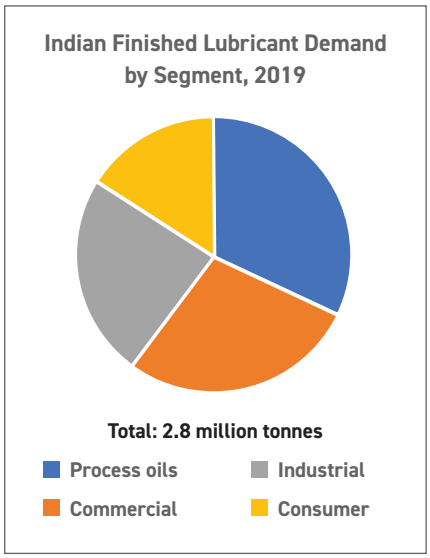
However, as we stand at the beginning of a new decade, the steam in the Indian economy seems to be fizzling. The Indian economy has registered continuous downward revisions in its economic growth. The latest estimates by International Monetary Fund (IMF) pegs the growth for the Indian economy at 4.8% for the fiscal year from April 2019 to March 2020, a sharp contrast to growth rates of around 8% year in the past.

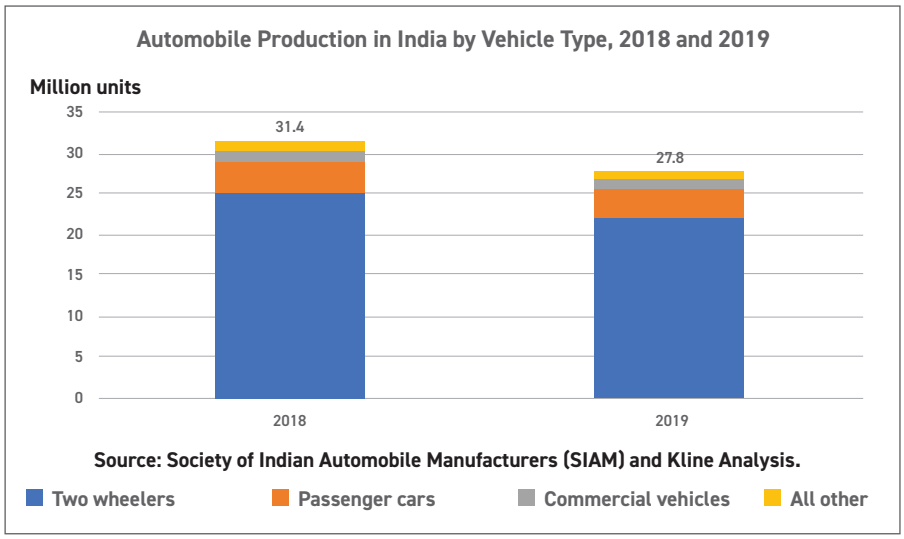
Several structural changes were introduced in the past few years. Demonetization of its currency notes and implementation of goods and services tax (GST) which, in principle, are good for economic health, created some disruptions in the economy. Moreover, weakness of the non-banking financial sector, growing non-performing assets (NPAs) and reliance on rainfall for a good agricultural harvest have contributed to the woes of the Indian economy. As a result, the Indian finished lubricant market has been hit.

India is not only a big automobile market but also a big manufacturer as well. After a period of sustained growth, Indian automobile production and sales declined sharply in 2019. Automobile production contracted by 10%-12% with the most severe shrinkage observed in commercial vehicles production.

In addition, weakness in key industrial segments persisted. Index for Industrial Production (IIP), a key indicator reflecting the health of industries in India, remained low. Consequently, the Indian finished lubricant demand managed a meager growth of 0.5% in 2019 from 2018. This is a significant reduction compared to historical growth rates of around 2%.

While the consumer segment (including passenger cars and two-wheelers) grew between 2.0% and 2.5% in 2019, the commercial segment (including commercial on-road and off-road vehicles and equipment) declined by around 0.5%. Demand for industrial lubricant registered minuscule growth. Overall, Kline estimates Indian finished lubricant demand at around 2.8 million tonnes including that for electrical transformer oils, white oils and rubber process oils.




## Rapid lube market change

While volumetric growth appears to have decelerated, India is making significant strides toward improving the quality of finished lubricants used. These changes are primarily driven to address the menace of air pollution and improve vehicles' fuel efficiency.

One key change that will have a profound impact on the lubricant quality in the automotive segment is the introduction of Bharat Stage VI (BS VI) norms. These are equivalent to Euro VI norms. To meet these stringent norms, the role of lubricant becomes important, however small. In general, there will be an accelerated switch toward lighter viscosity grades of engine oils. Currently, most OEMs recommend SAE 5W grades for new vehicles with some of them even recommending SAE 0W grades for select variants.

**Demand for industrial lubricants registered minuscule growth in 2019.**

A switch toward a lighter grade of lubricants is not only restricted in the engine oil category but is also apparent in transmission fluids. Until a few years back, SAE 80W-90 was the key grade used for factory fill and service fill by most passenger car manufacturers. However, to maximize the benefits of fuel economy, the use of lighter grades such as 75W-90 and 75W-85 has become prominent. Moreover, changing customer preference in the country is resulting in a surge in automatic variants of passenger cars. This trend is not only restricted in the premium car segment but has permeated to the mass market segment as well. Currently, automatic variants account for 10%-20% of new car sales for most OEMs in the country. This creates new demand for automatic transmission fluid, which is usually a synthetic lubricant.

On the commercial-vehicles side, compliance to BS VI is being targeted primarily with the help of hardware changes. However, a new market is opening for diesel exhaust fluid (DEF), which helps in scrubbing off harmful gases from exhaust before releasing them to the atmosphere. The market for DEF is currently small in India but will witness a steep growth in the coming years.

A key trend shaping the finished lubricant market in India is an extension in oil drain intervals. In the passenger car segment, the average recommended oil drain intervals are in the range of 10,000-15,000 kilometers. This has been a result of the growing proliferation of high-quality lubricants which are blended with Group II and III basestocks. Easy availability of basestock from nearby regions has helped the case.

Within the on-road commercial vehicles segment, average drain intervals have increased to 40,000-80,000 kilometers. Some OEMs recommend drain intervals upward of 80,000 for select models. SAE 15W-40 is the key viscosity grade, while API CI-4 Plus is the key API service category for engine oils used in commercial vehicles. The role of grades like SAE 10W-30 is small but growing.

A key feature of the Indian finished lubricant market is high demand for process oil products, which includes electrical transformer oil, white oils, and rubber process oils (RPO). These products account for close to one-third of the total finished lubricant demand. India is not only a key market for these products but a key exporter as well, serving markets in Africa, the Middle East, Southeast Asia and other parts of the world.

Several deliberations in the past have happened over formulating auto scrappage policy in India. At present there is no formal policy directing the life of a vehicle to


**India's economy is known for its resilience and often goes contrary to global trends.**

be used. As a result, the average vehicle life in India is much longer than that in Western markets. There have been several recommendations made in the draft policy guidelines which, if implemented, will help improve the age profile of vehicles in India. As more newer vehicles are added to the population and older vehicles are scrapped, demand for better quality lubricant will grow. This will result in an accelerated decline in demand for older specification oils.

## The average vehicle life in India is much longer than in Western markets.

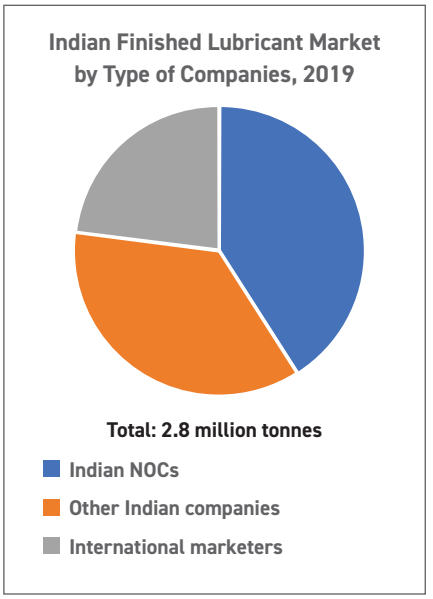
Agriculture is a major source of livelihood for a majority of the Indian population. With the growing mechanization of the sector, demand for finished lubricants has grown considerably. However, fortunes of the Indian agriculture sector are often contingent on rainfall each year, resulting in demand fluctuation from the sector.

Among the various industrial sectors, power (including both generation and distribution) is the major contributor to finished lubricants demand in India. The growth in industry, rapid urbanization and electrification of rural areas is resulting in sustained demand growth for products like transformer oil. Nonetheless, the country relies heavily on power gensets used as backup due to frequent power outages. These diesel-powered gensets typically use heavy-duty motor oils (HDMO) and contribute significantly to finished lubricant demand. Besides power, other notable end-use segments for finished lubricant demand include chemicals (including rubber processing), automobile manufacturing, auto components, general engineering, metals (both primary and fabricated) and mining.

Synthetic lubricants, although becoming increasingly popular in the consumer lubricant market, are a niche market in the commercial and industrial segment. Kline estimates that around a quarter of the consumer lubricant market is accounted for by synthetic and semisynthetic lubricants, while the penetration in commercial and industrial segments is less than 5%. The high cost of synthetic lubricants is a major impediment to the growth of synthetic lubricants. Their use on the industrial side is primarily driven by OEMs' recommendations.

Being the third-largest finished lubricant market, it is natural that the Indian finished lubricant market is fiercely competitive. The market is characterized by the presence of the three nationalized oil companies (NOC): Hindustan Petroleum, Indian Oil and Bharat Petroleum; international oil companies including ExxonMobil, Shell, Valvoline, Total; and Indian companies including Gulf Oil, Tidewater Oil, Apar Lubricants and Savita. Overall, Hindustan Petroleum is the leading marketer of finished lubricants (including process oils), accounting for around 18% of the market share, followed by Indian Oil. However, in the additized lubricant market (excluding process oils), Indian Oil is the market leader, followed by Hindustan Petroleum.

An interesting trend in the Indian consumer lubricant market is the emergence of OEM genuine oils. These brands, owing to a strong brand image of the OEM company, have successfully established themselves in the market. The success of these OEM brands largely owes to the growing service network of OEMs. Moreover, these brands are also being sold in the retail market, and a strong brand image of OEM often helps them grow.



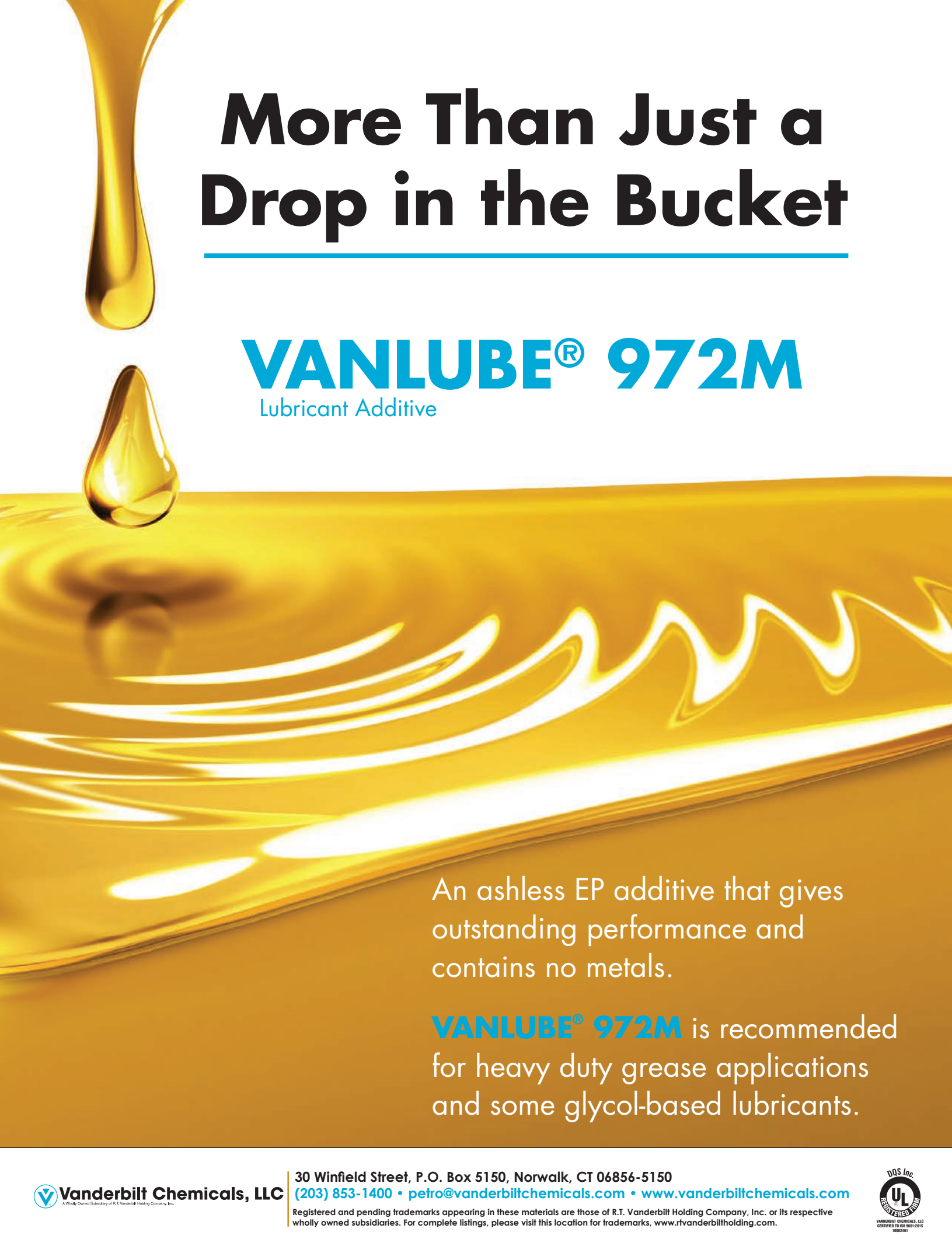

### What lies ahead?

While the overall economic growth may have subdued in the last year, it is a general consensus that India soon will recover to its usual growth trajectory as structural changes and policy corrections start bearing results. In the short term, IMF projects that the Indian economy will recover to grow at 6.5% in 2020-2021. These rates are certainly lower than historical highs but instill the confidence of continued demand growth in the finished lubricant market.

Overall, Kline forecasts that finished lubricant demand will grow at a CAGR of around 1.5% over the period 2019-2024. The consumer lubricant market will grow the fastest, while demand growth from the commercial segment will be the slowest.

Despite the reduction in growth rates, India remains the fastest-growing major finished lubricant market. In the times when growth is elusive in key markets like the U.S., China and Western Europe, the Indian finished lubricant market offers growth opportunities to lubricant marketers. Due to a transition toward better finished lubricant quality, the market outlook in value terms is brighter than the market outlook in volumetric terms.

*Hareesh Nalam is senior consultant (Energy) and Anuj Kumar is project manager (Energy) for Kline & Co. You can reach them at* ***hareesh.nalam@klinegroup.com*** *and* ***anuj.kumar@klinegroup.com****. Kline is an international provider of world-class consulting services and high-quality market intelligence for industries that include lubricants and chemicals. Learn more at* ***www.klinegroup.com****.*

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# Nicole Dörr

*It's time to rethink tribology says the scientific head of one of the world's largest science research centers.*

**By Rachel Fowler**
*Managing Editor*

**Nicole Dörr**
**The Quick File:**
Tribology researcher Nicole Dörr holds the title of scientific head of AC2T research GmbH, Wiener Neustadt, Austria.

Coming from a technical high school with specialization in mechanical engineering and polymer chemistry, she conducted her studies in chemistry at the Vienna University of Technology (TU Wien) from 1995 to 2000. In 2000 she joined CNRS CPE Lyon in France for the experimental work of her master's thesis on controlled radical polymerization within the European student exchange program ERASMUS. In her doctoral thesis she focused on trace analysis of petroleum products at the Institute of Petroleum (Austrian Research Centers Seibersdorf, now Austrian Institute of Technology) and obtained her doctorate from the TU Wien in 2003.

**Nicole Dörr** Photo courtesy of Jeschofnig.

Since April 2003 she has been a researcher at AC2T research GmbH, the Austrian Center of Competence for Tribology (AC$^2$T), located 25 miles south of Vienna, Austria's capital. After several positions related to lubricants and lubrication, she became scientific head of AC$^2$T in September 2016.

Dörr's professional work covers both fundamental research with academia and application-oriented research with industry. Main fields of activity are the formulation and assessment of lubricants and fuels. Particular focus is put on the laboratory-based simulation of lubricant and fuel degradation accompanied by the development of analytical methods to capture degradation pathways at the molecular level. Consequently, she also is involved in the development of oil sensor systems for condition-based and predictive maintenance. Ionic liquids as alternative lubricants are evaluated as base oils and additives for use in space units and components, among other uses. She has co-authored more than 60 peer-reviewed papers on lubricants and fuels and has contributed to seven patents.

Dörr recently received her habilitation (venia docendi) from TU Wien to teach students and supervise their theses in tribology. She is a frequent speaker at international tribology congresses and has worked as a guest lecturer at several universities. Nicole Dörr is vice president of the Austrian Tribology Society and an STLE member where she is active as vice PSC in the Lubrication Fundamentals Technical Committee.

**TLT: When was AC$^2$T founded and how did it evolve into the leading tribology research center in Europe?**

**Dörr:** AC$^2$T was established in 2002 as a result of the successful application to a competition announced by the Austrian government, which aimed at the establishment of centers of excellence. We have recently been granted funding for the third time and are now running our new research program until 2028.

I think several factors have made AC$^2$T one of the world's largest private R&D service providers in tribology. First of all, there is the will of the federal and provincial government to support centers with a single research focus in the long term. The competition among the 25 centers of competence in Austria requires us to regularly rethink our research priorities, which enables us to react quickly to developments in science and economy.

Furthermore, AC$^2$T operates as a one-stop shop, which means that our customers can contact us with any kind of tribological question. I see short distances to our highly dedicated experts as another key to success. For example, if I have a question about materials, I call my colleague Ewald Badisch, who sits in the neighboring office. Generally, the answer is fewer than 100 steps away from the question.

Finally, tribologists with decades of experience have led AC$^2$T since its beginning. We are particularly proud of professor Friedrich Franek, who was awarded the Gold Medal of the International Tribology Council in 2016, the most prestigious prize in the tribology community.

**Large-scale device for lubricant aging to produce test oils with defined used oil properties, up to 200 L per batch possible.** Photo courtesy of AC²T.

**TLT: What factors resulted in you pursuing a career with AC²T?**

**Dörr:** Throughout my education, first at the technical high school and later at the university, I have always had an affinity for petrochemistry. The first time I worked with lubricants through a traineeship in the lubricant laboratory of the Austrian oil company OMV Refining & Marketing, and since then I haven't been able to get away!

In 2001 the future course of my professional life was set. I was asked to join the planning committee with the aim of establishing a center of competence for tribology. The unique opportunity to build a business from scratch was tremendously exciting. Meanwhile I can look back on 19 years of development of AC²T, from the idea and vision to an internationally operating company with more than 150 employees.

My motivation to be active in tribology research, especially at AC²T? These are first and foremost the challenging R&D questions themselves; tribology typically requires an interdisciplinary approach. This is where I can use my education in mechanical engineering and chemistry.

I consider tribology as one of the most challenging sciences as sliding processes take place in an interface that is only a few micrometers thick or less. This requires, of course, appropriate instruments but also rigorous system analysis before we approach specific experiments and mathematical simulations. This means that R&D in tribology is never routine, I can actually say that I haven't been bored for a single day at AC²T! Finally, I have the possibility not only to contribute to AC²T but also to actively shape tribology.

To cut a long story short, tribology is highly demanding, and AC²T offers the creative environment to develop solutions.

**TLT: What are the research areas AC²T is involved in?**

**Dörr:** The research activities of AC²T are as manifold as tribology itself. We have, therefore, pooled our projects in four research areas.

*Sustainable lubrication* deals with formulation, assessment and benchmarking of lubricants and fuels including customized solutions for e-mobility and green technologies. Condition-based and predictive maintenance by sensor systems is another focus.

*Friction-optimized devices* evaluates tribo-systems for efficiency, reliability and endurance mostly at the component level. Measurement techniques for friction and wear are also developed here.

*Wear-reduction strategies* is focused on the development and testing of new materials, in particular coatings that must withstand harsh conditions such as high-temperature and corrosive environments.

Finally, *synaptic tribology* develops the lab-to-field approach combining computation and experimental simulation, digital twins and hardware-in-the-loop. The overall goal is to provide realistic models of tribological phenomena, multi-scale in space and time.

**TLT: What types of research and development involves your group at AC²T?**

**Dörr:** Our activities range from fundamental research to application-oriented R&D. Many approaches have started in our strategic research and are now well integrated into R&D services for the industry.

The idea for nano-scopic wear measurement was born at the beginning of AC²T. Now, the radioisotope concentration (RIC) method is part of tribometers and component tests, e.g., for piston ring cylinder liner contacts. In the field of lubricant evaluation, we have established our own aging laboratory to assess the stability of lubricants and fuels under realistic stress conditions. We use mass spectrometry to identify the reaction pathways of lubricant degradation at the molecular level. This approach distinctively improves the formulation and benchmarking of lubricants.

Our projects not only involve the respective experts but also a large number of bachelor's, master's and doctoral students. AC²T maintains a close cooperation with the TU Wien. Supported by the state government of Lower Austria, we have established an endowed professorship for tribology there, which has been held by Carsten Gachot, originating from Saarland University, since 2016.

Beyond that, we also benefit from the knowledge of visiting scientists such as Yip-Wah Chung from Northwestern University and Ichiro Minami from Iwate University in Japan, now with Luleå University of Technology in Sweden.

**Clean-room laboratory with high-resolution mass spectrometer, preparation of oil samples. From left to right: Nicole Dörr and Andjelka Ristic.** Photo courtesy of AC²T.

## Tribologists can no longer do more of the same thing.

**TLT: What technical expertise and instrument capabilities make AC²T unique?**

**Dörr:** We have experts from all core disciplines that contribute to tribology: mechanical engineering, physics, chemistry, material science, mathematics, information technology, electric engineering and electronics.

However, I consider AC²T to be much more than just the sum of its parts. I'll give you an example from my field of work. We successfully build sensor systems for the condition monitoring of lubricants. The lubricant experts identify the critical factors of lubricant aging and develop laboratory-based methods to simulate the application in the laboratory. Our sensor designers use this input to build a sensor system and evaluate its functionality and reliability via simulated lubricant aging. Evaluation algorithms are implemented with the data obtained together with an easy-to-use interface for the operator. The interaction of lubricant chemists and mechatronics engineers is what makes customized solutions for condition-based and predictive maintenance possible.

Regarding equipment, we strive for "uniqueness through completeness." We have well-equipped laboratories for tribotesting as well as material, lubricant and surface characterization. Most of our tribometers have been developed in projects with and for companies. For mathematical simulations, e.g., using molecular dynamics, we run our own computing cluster.

Here are a few other highlights. With our large-scale device for lubricant aging, we produce well-defined used oils in larger quantities, so that our customers can test the effect of lubricant aging also on their components with their test benches. By laser cladding, we functionalize complex shaped structures with a wear-resistant coating, e.g., on 3D-printed light-weight parts as possible components for aircrafts. The RIC method allows the measurement of wear rates in nm/h under loading conditions close to reality while the tribometer being in a normal laboratory since the RIC works well below the thresholds for radioactive substances given by law.

**TLT: I notice you're a scientific head. Can you tell us the purpose of this function and how it enhances AC²T?**

**Dörr:** The main tasks of the scientific head are to push and control the scientific progress of the projects and to design the strategic direction of AC²T. The scientific management consists of two key researchers, Ewald Badisch and myself. This is owed to the diversity of tribological topics and the fact that it is practically impossible for an individual to have a comprehensive overview of tribology. While Ewald deals especially with material topics, I am responsible for questions about lubricants and lubrication.

In order to maintain the quality of our R&D activities and thus the benefit for our customers at a high level, we as scientific heads emphasize optimal interaction between the research areas within AC²T's specific expertise. In view of the challenges posed by digitalization, we have established a coordinator for data science who is in charge of supporting the research areas on data acquisition and analysis.

**TLT: Can you tell us a little about your research partners and research project funding?**

**Dörr:** Our research partners are more than 30 universities and research centers as well as more than 80 companies, mainly from Europe. But our collaborations are international, including a number of research activities with U.S. partners: Ali

Erdemir from Argonne National Laboratory, Pranesh B. Aswath from University of Texas at Arlington and Ashlie Martini from University of California, Merced.

We are engaged in a variety of collaborative activities, ranging from pure contracts via national and European projects to our research program *InTribology*, the largest project with a budget of $12 million (€11) per year. Within the frame of *InTribology*, we conduct fundamental research (strategic research) with our scientific partners, with the aim of using the findings in application-oriented projects with company partners.

The budgets of the more than 100 individual projects are based on a mix of cash and non-cash contributions from the partners as well as on a share from public funds. Since we are launching our new research program in April 2020, this is perfect timing to discuss cooperation opportunities!

**TLT: What do you think is the greatest challenge facing tribology research in the next 20 years?**

**Dörr:** Of all global trends, digitalization, electrification and green technologies will have the greatest impact on tribology. For us tribologists, this means no longer doing more of the same thing but rethinking tribology.

Digitalization is driven by data science and therefore requires appropriate data available in sufficient quality and quantity. Using data-driven discovery and engineering, tribological phenomena will be more and more designed, evaluated and controlled by methods of artificial intelligence, e.g., machine learning for the prediction of system failure. Already we are conducting tribo-metrical experiments in which sensor data in the range of terabytes each are acquired and analyzed. Finally, I expect that the development of robust sensors and algorithms for real life applications will be triggered by digitalization.

## We need to rethink tribology.

Increasing efficiency and reducing the carbon footprint are currently the drivers of R&D in mobility. There are intensive activities for the electrification of vehicles, but the fundamental tribological mechanisms related to their components and drivetrains are by far not as well understood as for internal combustion engines and other powertrain components. In particular, the development of new equipment is required to investigate the influence of high relative motion, electromagnetic fields or even current flow, among others, on tribological performance. Tribological R&D on hydrogen-powered engines will also be driven parallel to electrification.

Green technologies such as biologically degradable lubricants are able to outperform conventional lubricants but are currently not widely used mainly for cost reasons. For example, synthetic esters are more expensive than mineral oil-based lubricants. There are concrete developments to replace the base oil with water or to use only water as the lubricant. This obviously necessitates the re-design of entire tribological systems and components. Legislation could accelerate the implementation of such green technologies.

In addition, R&D cycles are shortening, which requires faster upscaling for market entry. We meet this challenge with our lab-to-field approach. Two important elements make up the lab-to-field approach: First, we transfer applications into realistic laboratory methods and simulation models. Second, experiments and mathematical simulations are interwoven so that each method may be used to its full potential.

Although at first sight these developments seem threatening, I am convinced that we can manage them because tribology is interdisciplinary in nature.

*You can reach Nicole Dörr at* ***Nicole.Doerr@ac2t.at.***


**From left to right: Bony Vattappillil, Ommeaymen Sheikhnejad, Nicole Dörr, Marcella Frauscher, professor Friedrich Franek, Christoph Schneidhofer.** Photo courtesy of AC²T.

# Daniela Fritter

*This physical chemist with Clorox uses tribology to solve problems with personal care, food and cleaning products.*

**By Rachel Fowler**
*Managing Editor*

**Daniela Fritter**
**The Quick File:**

Daniela Fritter is an Associate Research Fellow in the Advanced Measurement Sciences department of Clorox R&D. She earned her doctorate in physical chemistry at the University of California, Los Angeles, studying the evolution of droplet patterns on surfaces through growth and coalescence (breath figures). In post-doc work for the Air and Industrial Hygiene Lab in Berkeley, Calif., she investigated particle resuspension and deagglomeration in a model system to predict the effect of impaction in air samplers.

Fritter began her career at Clorox in 1991 working on upstream technology for hard surface cleaning and laundry and fat replacement in salad dressings. She also spent three years in product development in the Hidden Valley group, leading multifunctional teams in bringing salad dressing line extensions and product improvements to market. Since 2002 she has been the lead rheologist for Clorox, providing technical guidance and insights to enable optimization and innovation in product categories across the portfolio. In that time, she also has built tribology capability in cleaning, foods and personal care applications, owing to the overlap between the two disciplines. Fritter holds patents on surfactant thickening of cleaning gels, delivery of oil from polymer matrices and hand grippability of cleaning pads. She is a member of ACS, AOCS, AIP, SOR, STLE and SWE.

**Daniela Fritter**

**TLT: How did you get interested in rheology and tribology?**

**Fritter:** As a physical chemist, I've always been curious about the phenomena that underlie macroscopic observable behavior and appreciative of physical models that both explain what's going on and provide the practical levers to pull to make desired changes. This mindset works well in the CPG (consumer packaged goods) industry where the consumer's sensory experience is an important component of overall product performance: how it looks in the bottle, the scent on removing the cap, how it pours, how quickly the stain disappears.

I was first drawn to rheology, the study of how materials deform or flow under stress, because it provided a way to quantitate practical behavior I directly experienced with my own eyes or hands—appearance and feel of the product on shaking or dispensing or rubbing it on surfaces, cling to vertical surfaces, ease of spraying, etc. But rheology also has a theoretical underpinning that addresses how colloidal forces interact with the ingredients and the mixing process to form a product's microstructure, providing the link between the molecular and the macroscopic that allows us to design and optimize products for manufacturability and consumer preferred flow.

While much of the consumer's real-time interaction with a product is rheological in nature, it's sometimes necessary to invoke tribology to explain some new and unexpected behavior when the moving surfaces come close enough to interact. A personal care product might pull more on the skin during application, or a salad dressing might have a fattier mouthfeel, in a way that is not predicted by rheology alone. Cleaning wipes made with the same substrate and cleaning fluid can be experienced very differently as they're pulled across different surfaces or soils. Such phenomena often have tribological roots.

**TLT: What are the methodologies you use to measure performance?**

**Fritter:** We have technical performance criteria and associated manufacturing specifications across all of our product forms to ensure consistency in product quality and consumer satisfaction. These might concern things like cleaning performance, antimicrobial efficacy, packaging stability, product shelf life and aesthetic features like color, fragrance and viscosity. We generally align with CPG industry standards but also develop in-house proprietary methods to meet specific analytical and predictive needs. Because the CPG industry is experiential and sensory driven, many of our challenges involve translating

There is still much we don't understand about the tribological behavior of human skin.

qualitative product attributes into hard numbers that relate to the consumer experience in a meaningful way.

With respect to rheology, an empirical spindle-in-beaker viscometer is commonly used to assess simple formulation or process changes, track stability or for manufacturing quality control. However, this type of measurement typically does not account for shear rate dependence and might not capture important consequences of more complicated changes to the product matrix. For this purpose, a stress-controlled rheometer with a concentric cylinder and either cone-and-plate or parallel plate geometries is a standard tool for more in-depth flow characterization of thickened fluids and soft solids.

In viscometry mode, a material is sheared in rotation until a steady-state viscosity is reached. A profile of the viscosity as a function of shear rate describes the general flow behavior of the material under different practical conditions. Low shear rates correspond to flow under gravity or suspension ability; medium shear rates correspond to shaking, stirring and pouring; high shear rates correspond to pumping, spraying and hydrodynamic lubrication (involving always a fully intact fluid film between the surfaces). In dynamic mode, small oscillations are applied to map the viscoelastic material response, allowing deeper insights into interactions between particles and microstructural behavior. Characterizing parameters such as relaxation time or critical strain can be related to actives delivery or gel-like appearance.

Rheological measurement is based on well-defined boundary conditions and long-established equations of fluid flow; scaling relationships and prediction of practical behaviors are reasonably well understood for many types of systems. With tribology, physical characterization is more complicated and chemistry specific, often involving multiple phenomena, multiple scales and temporal changes including wear during the course of measurement. This results in a variety of empirical tools and techniques that are highly specific to the problem being studied. In the realm of consumer products, for example, widely different methods have been used for assessing the effect of floor cleaners on slip resistance,[1] the effect of shampoos and conditioners on the feel of human hair,[2] sensory perception of food products in the mouth[3] and personal care products on the skin[4] and mechanisms of hard surface cleaning.[5]

**TLT: Describe a tool or method you used to solve a tribological problem.**

**Fritter:** One of our technical teams was developing cleaning pads for use on kitchen or bathroom surfaces. The pad is dry to the touch but impregnated with cleaning ingredients that release when wetted with water. The resulting suds can migrate between the hand and the pad, causing the hand to slip during cleaning. The team noticed that incorporating natural pulp fiber into the hand-facing layer resulted in better grip during cleaning, and wanted to validate this benefit with technical data rather than spend money on consumer testing. So I developed a method to quantitate the hand gripability of the cleaning pad in a reproducible and statistically discriminating way, while emulating as closely as possible real-use conditions by using human operators and a platform on load cells that can accommodate a human hand in a wiping motion.

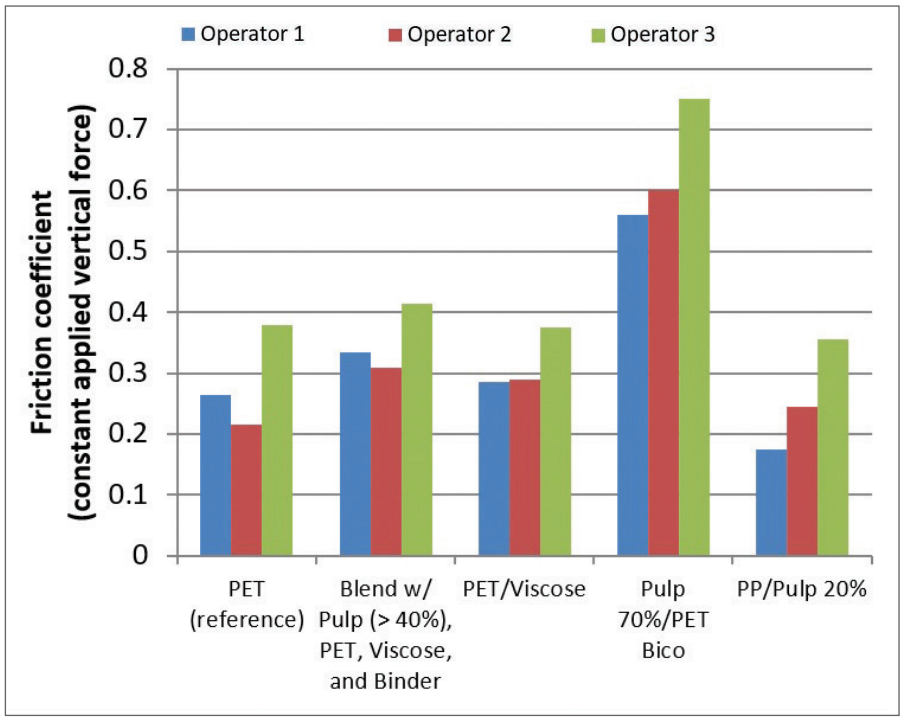


Figure 1a. **Sliding friction coefficients obtained with human operators sliding their hands across wetted and immobilized cleaning pads under controlled conditions (applied vertical force between 1 and 5 pounds, reciprocating path length 3.5", 1 second per back-and-forth cycle). Cleaning pads are of similar composition and construction except for the hand-facing layer, which contains the test compositions of synthetic-pulp blends as labelled in the chart.**

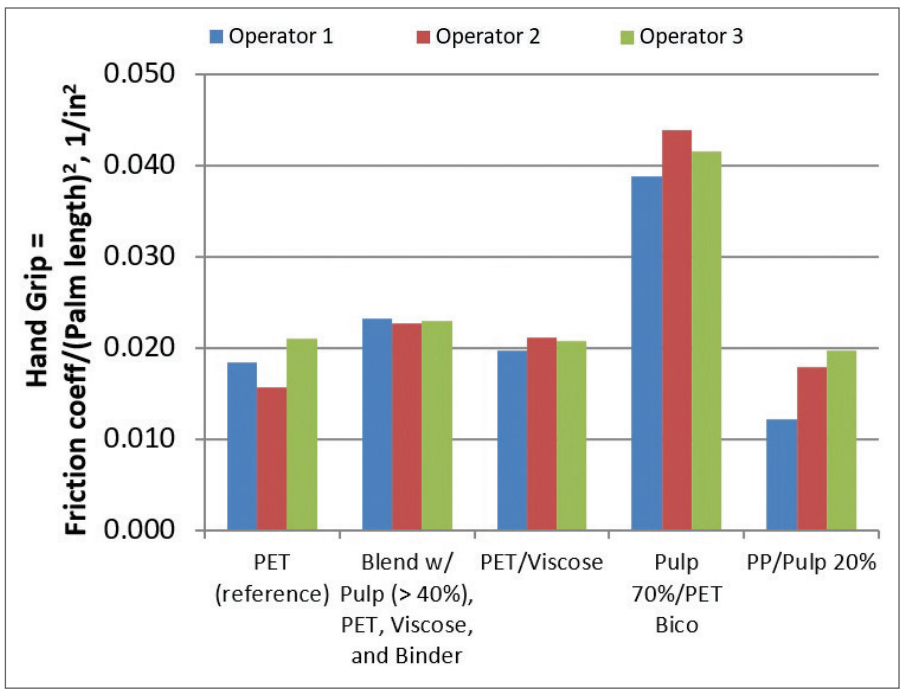


Figure 1b. **The data of Figure 1a, where the friction coefficient has been divided by the square of the palm length of each operator, creating a new variable called hand grip. (Palm length is 3.80" for Operator 1, 3.70" for Operator 2 and 4.25" for Operator 3.) The two materials with at least 40% pulp have statistically higher hand grip versus PET and PET/viscose (synthetic/semisynthetic materials containing 0% natural pulp). Hand grip is significantly higher for the blend with >40% pulp versus either PET or PET/viscose, using t-test of values across evaluators at 90% confidence.**

The cleaning pad was primed in a controlled way to wet it and release the suds, then affixed to the platform with the hand-facing side up. Applying some pressure, the operator slid his or her hand back and forth across the immobilized pad to generate lateral and vertical forces from which sliding friction coefficients were calculated. To minimize variability and focus the work, our protocol specified a narrow range of vertical force and speed within a consumer relevant window. The operator monitored the applied vertical force and made adjustments in real time to stay within a 1-5-pound range. The path length of the reciprocating motion was fixed, as was the timing of each back-and-forth stroke, resulting in a velocity between 15-20 cm per second.

The values of friction coefficient collected in this way were reproducible by the same operator. In addition, the same relative product differences were seen by all operators, although the values for Operator 3 were systematically higher (*see Figure 1a*). We can attribute this to the larger hand size of Operator 3 resulting in a lower contact pressure by virtue of keeping the applied vertical force constant across operators. A lower contact pressure translates for wet skin into a higher friction coefficient.[6] This suggests that changing the method to standardize the contact pressure instead of the applied vertical force could remove the bias due to hand size.

Alternatively, we accounted for the hand size difference by applying a scaling factor to the friction coefficient, thus obtaining statistical differentiation to quantitatively demonstrate the effect of pulp. Figure 1b shows the scaled variable of Hand Grip across three operators for a series of cleaning pads in which the hand-facing layer ranged in pulp content from 0%-70%. This and other data allowed us to make a technical claim for proprietary advantage,[7] specifically that the use of natural pulp at levels of at least 40% in the hand-facing layer lessens slip of the cleaning pad in the hand, ultimately translating into a better consumer experience.

**TLT: What area would you most like to explore?**

**Fritter:** There is much we still don't understand about the tribological behavior of human skin, a soft biomaterial charac-

terized by nonlinear viscoelastic material response and a complex surface structure. The main contributor to skin frictional behavior is thought to be adhesion friction caused by attractive surface forces at the skin-material interface, while deformation usually plays a lesser role. I'd like to better understand the nature of the localized adhesion forces during skin contact with a given surface, and which chemical and geometric factors have the biggest influence. I see this as analogous to understanding how colloidal forces influence aggregation to link the molecular to the macroscopic in rheological flow.

**Rheological measurement is based on well-defined boundary conditions and long-established equations of fluid flow.**

Testing with human subjects (in-vivo) still provides the most realistic results, but ultimately being able to move to more controlled and sophisticated in-vitro measurements would save time and increase the scope of variables that can be investigated, and with higher precision. This could be achieved with better polymeric skin mimics and sensory feedback loops that more closely approach the human response, coupled with robotics and AI to handle the larger data processing requirements.

*You can reach Daniela Fritter at* ***daniela.fritter@clorox.com.***

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# 2019 STLE Certification List

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United Oil and Grease

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**Jason Beh Kee Seang**
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TLT salutes these individuals on their efforts. For more information on the certifications or to schedule an exam, contact STLE certification and section relations manager Gina Cairo at ***gina@stle.org***, 847-825-5536.


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# The problem with judging tackiness

*Researchers seek a quantitative method to help formulators make better decisions.*

**By Andrea A. Aikin**
*Contributing Editor*

**Greases are used** in a number of different industrial fields, ranging from construction, mining and transportation to the food industry. The purpose of using greases in these different applications is to reduce frictional forces to protect industrial components from wear and corrosion. As a semi-solid, a grease is better able to adhere to a metal part than an oil. Grease performance hinges on the interaction of different properties, including adherence to the substrate material (i.e., adhesivity), cohesion and tackiness.

Identifying the appropriate grease for a given application can be challenging as there is no established quantitative method that accurately measures the grease tackiness. A grease can have too much or not enough tack for a particular project. Tackiness is defined as the cohesiveness or stickiness of a material. Words like glueyness, ropiness and viscosity are used to describe the resistance of a liquid to flow or shear. Properties like apparent viscosity, resistance to oxidation and structural and mechanical stability also can indicate whether a grease is suitable for a particular application.

STLE-member Erik Willett, technical director at Functional Products Inc. in Macedonia, Ohio, identifies three things the grease market currently lacks:

- A way to know how tacky a grease is before customers try or buy it.
- A test method to reproducibly QC tackiness for each batch of grease.
- A way to correlate and optimize both the obvious and subtle effects of tack to a specific application.

While instrumentation companies such as Falex, Koehler and others are working toward reproducibly measuring grease tackiness, Willett notes, "A simple and informative number for both formulators and end-users to make informed decisions on the tackiness of a grease is still in the future."

## Working with grease

STLE-member Anoop Kumar, a senior staff scientist with Chevron Inc. in Richmond, Calif., states, "Measuring the tackiness of grease is often perceived as a significant screening criterion in the selection of grease." While no standard test methods are currently available to reproducibly measure tackiness, Kumar notes that efforts are being made to "quantitively measure the tackiness of greases and standardize the tests."

**There is no way to judge a grease's tackiness before the end-user tries it.**

Researchers are seeking ways to standardize grease tackiness and test procedures.

NLGI publishes an NLGI consistency number that expresses a measure of the relative hardness of a grease used for lubrication. NLGI's classification is reproduced in ASTM D4950 (Standard Classification and Specification of Automotive Service Greases)[1] and SAE J310 (Automotive Lubricating Greases).[2] However, the NLGI consistency number alone is not adequate for specifying the grease a particular application requires.

When discussing grease tackiness, ASTM D2979 (Standard Test Method for Pressure-Sensitive Tack of Adhesives Using an Inverted Probe Machine)[3] may be mentioned. Tack is a measure of the force needed to separate the adhesive and the adherent at their interface shortly after they have been brought into contact under a defined load of known duration at a defined temperature. While this particular ASTM method is used to measure adhesion, it is not appropriate for measuring the tackiness of grease.

Several perception-based qualitative approaches are currently used to measure grease tackiness. These include a test colloquially known as the fingertip or spatula test. Kumar describes the test as placing a blob of grease between the thumb and index finger. The thumb and index finger are then pulled apart until the string of the grease breaks.

Kumar says, "The distance and force required to separate them determines the extent of tackiness of the particular grease." However, this test is highly variable depending on the person performing it. Currently, there are no standard test methods to numerically measure the tackiness of greases, although work is occurring to develop such tests. This developmental work is focusing on the same principle as the fingertip/spatula test.

John Sander, vice president of technology at Lubrication Engineers, Inc., in Wichita, Kansas, notes, "A quantitative number has not been really necessary." End-users often like the eye candy effect of placing a grease sample between their finger and thumb and watching it string, although many have found these results do translate into performance in the field. Impact tests also are used to assess tackiness, but these also lack a numerical result.

## No standard test method reproducibly measures grease tackiness.

**Potential measurement methods**

A 2019 Tribology Transactions paper titled Development of Grease Tackiness Test discusses how a test method using a standard tribometer was able to differentiate different greases.[4] A tribometer measures tribological quantities between two surfaces that are in contact, including the coefficient of friction, friction force and wear volume. The article notes that "working" the grease before conducting the test has a significant impact on grease tackiness. While the specific test method described in the article was shown to provide similar results to more expensive and time-consuming tests, it is not generally accepted in industry.

Willet adds, "Equipment is being developed to quantify tackiness by pulling threads of grease with a probe and measuring the thread length at the breaking point." This is similar to the process of measuring string length in oil with the ductless siphon test.

Willett notes, "Grease polymers all impart different 'types' of tackiness to grease. Some greases become very stringy, others have more of a tough impact-resistant quality to them, and some polymers might have no discernable tackiness but improve stability in water spray off and worked-cone penetration." It would be useful to have a system capable of classifying these different types of tackiness for different applications.

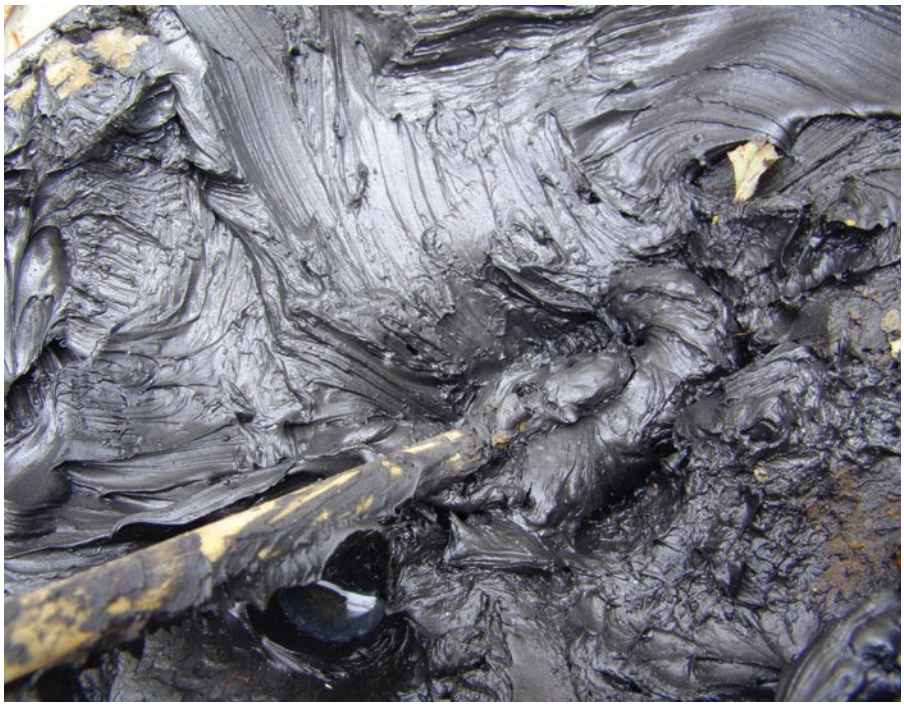
**Quantifiable data**

A 2018 article in the peer-reviewed journal Tribology Letters notes that tackiness of industrial greases is not a single value as tackiness changes with experimental conditions.[5] However, it might be possible to develop a map of grease tackiness with respect to changing experimental or working conditions (e.g., retraction speed, grease film thickness, applied load, temperature, etc.).

## Tackiness is defined as a material's cohesiveness or stickiness.

Functional Products collaborated with the Falex Corp. in Sugar Grove, Ill., to develop the Falex Tackiness Adhesion Analyzer (TAA). The device quantitatively measures the tackiness and adhesion properties of both greases and other lubricating materials by executing and recording scientifically determined values related to measuring tackiness, including pull-off force, separation energy and retraction speeds. These values are used to calculate the tackiness number, which is calculated by dividing the thread length by the separation energy.

The Falex TAA device can be used to profile grease tackiness with respect to changing temperature and retraction speed. The device's goal is to replace the fingertip test by directly measuring adhesion, tackiness and thread length under unique test conditions. Falex believes this number has application in grease specifications and will permit complete characterization with respect to tackiness.



**Conclusions**

Currently customers evaluate tackiness subjectively by testing to evaluate the effectiveness of a particular grease for a specific application. While this process addresses an immediate problem, it doesn't create a clear path forward for future work.

Ultimately, developing a tackiness number that could complement the NLGI consistency grade would allow both formulators and end-users to make more informed decisions.

*Andrea R. Aikin is a freelance science writer and editor based in the Denver area. You can contact her at* ***andrea.r.aikin@gmail.com****.*

## FURTHER READING

- For more information on a preliminary study of the development of a grease tackiness test, see the article in Tribology Transactions.[4]
- For information on a new methodology based on approach-retraction curves that seeks to objectively measure adhesion and tackiness in industrial greases, see the article in Tribology Letters.[5]

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# Metalworking Fluids: Minimizing aluminum staining

*Strategies, including screening tests, are discussed to assist with providing approaches for protecting aluminum alloys.*

**By Dr. Neil Canter**
*Contributing Editor*

**The importance of preventing aluminum staining is increasing as auto manufacturers incorporate the metal into their vehicles to reduce weight and increase fuel efficiency.**

## KEY CONCEPTS

Aluminum staining is caused by a number of factors including high pH that leads to the dissolution of the protective oxide layer coating the metal.

Three different mechanisms that aluminum stain inhibitors utilize to protect the metal are chemisorption, formation of complexes with corrosive agents and a protective film acting as a physical barrier.

The recommended test method is to immerse aluminum coupons into fully formulated metalworking fluids at alkaline pH values (at a minimum of 9.2).

Future demand for more effective corrosion/stain inhibitors will increase due to the growing use of aluminum in combination with other materials.

**The ongoing drive** to improve efficiency has led end-users to produce machinery that is lighter in weight. A case in point is the automotive industry where original equipment manufacturers (OEMs) are facing the challenge of complying with more challenging fuel economy and emissions regulations.

This trend has led OEMs to incorporate lighter weight alloys into their vehicles. A key example is aluminum. In 2015 the Ford Motor Co. decided to transform its best-selling F-150 pickup truck from a steel to an aluminum alloy body[1]. This process reduced the weight of the newly designed truck by more than 300 kilograms. The alloy used by Ford is a 6000 series wrought aluminum.

The result of the move by Ford and other end-users is an increase in the need for metalworking fluids (MWFs) that can be used to form and machine aluminum alloys and also have the versatility to form and machine other alloys such as steel and copper. But there are challenges faced by MWF in working with aluminum. One of those challenges is understanding and minimizing the degree of staining that can be seen on fabricated aluminum parts.

The purpose of this article is to discuss the origin of aluminum staining and to discuss what approaches can be taken to minimize it. Input on the issue was obtained from industry experts who have perspectives from the additive and formulator standpoints. The following individuals were contacted: **Harish Potnis**, ANGUS Chemical Co., **Stephanie Cole,** Clariant, **Dr. Yu-Sen Chen,** Dober Chemical, **William Harwood,** Italmatch Chemicals Group, **Jennifer Lunn,** JTM Products Inc., **Dr. Britt Minch,** The Lubrizol Corp., **Kevin Saunderson,** New Age Chemical.

**Cause of aluminum staining**

STLE-member William Harwood, global product manager, Water Based MWF for Italmatch SC, LLC in Cleveland, identifies three causes of aluminum staining. He says, "Aluminum is naturally protected from corrosion since it reacts with oxygen forming a stable oxide layer. Under alkaline conditions present in water-based metalworking fluids, the oxide layer dissolves, and aluminum can show signs of corrosion/staining which range from light yellow to very dark gray. A second cause is the occurrence of galvanic corrosion when two dissimilar metals are in contact in an aqueous environment. For example, while machining aluminum that is in contact with the cast iron/steel bed of the machine tool, aluminum will tend to corrode in preference to the steel alloy. A third cause is high chloride levels (that may be present in water used in machining operations) increasing the chances for aluminum staining."

STLE-member Stephanie Cole, formulation chemist with Clariant in Mt. Holly, N.C., also lists three causes for aluminum staining. She says, "Aluminum staining can be caused by filiform corrosion, galvanic corrosion and poultice corrosion. Filiform corrosion is caused by the imperfections of other metals used in various aluminum alloys. Galvanic corrosion happened upon exposure of aluminum to other metals in the presence of electrolytes such as salt water. Poultice corrosion is the process that occurs when the natural aluminum oxide layer degrades."

STLE-member Dr. Britt Minch, research manager, Metalworking, for The Lubrizol Corp. in Wickliffe, Ohio, says, "Aluminum and its alloys are usually not the first metallurgy that comes to mind when discussing corrosion. Protective oxides cover aluminum surfaces and protects the metal surface from the environment. Corrosive ions such as chlorides and sulfates can penetrate the protective layer leading to pitting. Metalworking fluids are generally formulated at a pH greater than 9 to minimize both ferrous corrosion and biological activity. As a consequence of the high pH, the protective oxide layer is etched away by the metalworking fluid. One of the sensitivities of aluminum machining is its tendency to stain at high pH."

STLE-member Dr. Yu-Sen Chen, R&D director for Dober Chemical in Woodbridge, Ill., says, "The destruction and/or dissolution, of aluminum's protective oxide film and or/other protective film/layer on the aluminum surface causes staining."

STLE-member Harish Potnis, global technical manager, Metalworking Fluids, for ANGUS Chemical Co. in Buffalo Grove, Ill., indicates that aluminum corrosion/staining is the result of metal corrosion during the metalworking fluid process. He says, "Aluminum staining can be influenced by several common negative factors that include high pH, alkalinity, specific acids and water quality."

## Stain inhibitors will likely see significant growth in the automotive market.

**Aluminum stain inhibitors**

Minch states that there are a variety of chemistries available on the market today that can be used to protect aluminum alloys. He says, "The chemistries differ greatly in what they can offer in terms of performance across a range of fluid types, water hardness levels (for water-based fluids), pH ranges and even metallurgies. Phosphorus-based corrosion inhibitors are among the most effective inhibitors because they have broad applicability across all fluid types and pH ranges. The phosphorus head group has an extremely strong affinity for the aluminum surface. Many different types of phosphorus-based inhibitors are available, some of which are optimized to provide surfactancy, improve metalworking fluid hard water compatibility and/or improve fluid longevity."

Minch continues by discussing other inhibitors based on sulfonates, carboxylic acid/amine salts, polymers and silicates. He says, "Certain amino sulfonates have been used as corrosion inhibitors for aluminum alloys, but they tend to be more limited in terms of effective pH range. The sulfonate-based inhibitors tend to be limited to fluids with significant concentrations of oil to allow for their solubilization. Carboxylic acid/amine salts can be useful in certain conditions but tend to be most limited in effective pH range and are only useful in lower water hardness levels. A few polymeric inhibitors that are available in the market can be quite effective in emulsifiable oils or high-oil semi-synthetic metalworking fluids, however, they tend not to be compatible in synthetic fluids. Finally, silicates as sodium or potassium salts are commonly used inorganic corrosion inhibitors for aluminum alloys. Their main drawbacks are they tend to be used at high pH values (>9) and may leave an undesirable, tacky residue on the workpiece or the machine tool."

Potnis feels that while several aluminum corrosion inhibitors are available, certain formulary and regulatory requirements often can impact their selection and use. He says, "Some of the most common chemistries include sodium silicates, phosphate esters, amine salts and amine carboxylates. Silicates, while readily available, can be difficult to incorporate into a formulation and can eventually precipitate over time leading to filter blockage. Phosphate esters are widely used as extreme pressure (EP) additives, but not all types are good stain inhibitors, and they are known to encourage microbial growth. Amine salts and amine carboxylates can be effective, but water hardness and chloride variation can be problematic."

Harwood lists three types of aluminum stain inhibitors: phosphates, silicates and triazoles/thiadiazoles. He says, "Phosphates in the form of phosphate esters are effective but can be prone to fungal attack and restricted upon disposal of the depleted water-based metalworking fluids. Those phosphate esters containing higher ethylene oxide levels may also generate high levels of foam which is not desirable. Silicates can also inhibit aluminum staining but may not be compatible with the metalworking fluid formulation. All of these inhibitors are typically used at low treat rates (about 0.5%) in the metalworking fluid concentrate."

Cole divides aluminum stain inhibitors into two categories: inorganic and organic based. She says, "Inorganic stain inhibitors are available but require additional processing and a change of surface profiling. In contrast, organic types can be applied simply but are temporary at best."

**How inhibitors function**

Aluminum stain inhibitors function via three different mechanisms (chemisorption, complex and protective film) according to Potnis. He says, "The chemisorption principle involves the inhibitor forming a protective layer via a chemical reaction/bond on the metallic surface. In solution, an aluminum stain inhibitor can form a complex with corrosive agents preventing them from staining the metal surface. A physical barrier can form a protective film to protect the base metal from staining."

Cole differentiates the approaches used by inorganic and organic aluminum stain inhibitors. She says, "Inorganic corrosion inhibitors create a chemically bonded barrier, while organic inhibitors produce a hydrophobic film that promotes water repellency."

Harwood provides insight on how inhibitors use an adsorption process. He says, "Most inhibitors that use a surface adsorption mechanism where they are capable of donating a pair of electrons through the presence of oxygen, nitrogen, phosphorus and sulfur atoms in these molecules. Silicates do not operate using this mechanism but rather provide stain inhibition through a chemisorption process."

Chen says, "Aluminum stain inhibitors either form a strong and adherent oxide film, form a protective layer or chemically adsorb to the metal surface."

Minch feels that the mechanism of aluminum protection will vary depending on the chemistry used as the inhibitor. He says, "For example, phosphorus-based corrosion inhibitors chemically adsorb to the metal surface leaving a thin barrier layer to protect the underlying metal surface. Regardless of the inhibitor type, only a few layers of the inhibitor will attach to the surface and organize to form a protective layer, thus the transient nature of these types of corrosion inhibitors."

**Performance requirements**

Cole believes an aluminum stain inhibitor must be effective in a variety of formulations and yet not interfere with other additives required in complex MWF formulations. She says, "An aluminum stain inhibitor must work in a wider range of metalworking fluid types but not disrupt the formulation stability, not disrupt ferrous metal protection and not reduce reserve alkalinity."

Minch says, "When choosing an aluminum stain inhibitor, there are multiple performance parameters that need to be taken into consideration. First and foremost, the main decision point for a stain inhibitor is whether it will provide the desired level of corrosion protection for all metal alloys that are expected to encounter the fluid. The pH of the metalworking fluid many times will limit the choices available to the formulator. Long-term fluid stability may also be a driver in the choice of inhibitor. For example, silicates may precipitate out of solution or even plate out on the workpiece, lowering the effectiveness of the inhibitor over time. The formulator would also be wise to look at hard water stability of the fluids to ensure that the stain inhibitor does not have any negative impact."

Chen focuses requirements for an aluminum stain inhibitor on effectiveness and performance. He says, "Dosage, performance under different corrosive environments and effective pH range are some of the criteria that need to be examined in selecting an aluminum stain inhibitor. Performance of the inhibitor should be evaluated in a complete formulation in the presence of other inhibitors and components. Other factors to consider are ease and stability in formulating, meeting environmental requirements and availability."

Potnis indicates there are two important considerations to ensuring performance across all applications: compatibility with other formulator components and multi-metal compatibility. He says, "Additional performance considerations include but are not limited to, functionality in elevated pH environments, vapor phase corrosion performance and impact on microbial growth."

Harwood states that a formulator making a selection must keep in mind formulation compatibility and inhibitor stability. He says, "The inhibitor should be compatible with the formulation that is being prepared. Ensure that the formulation is inherently low staining/low pH first, then add the inhibitor. Some inhibitors are susceptible to hard water (calcium and magnesium water salts) and can precipitate out of solution. Some inhibitors are not stable in concentrates which have a water content above 5%."

**Amines**

Amines fulfill a number of important functions in a MWF, but aluminum stain inhibition is not one of them. Minch discusses why formulators need to consider what amines to work with in minimizing staining. He says, "Alkanolamines are commonly used in metalworking fluids to raise the pH of the fluid and to salt acidic components. These alkanolamines are a critical tool in the formulator's toolbox, but they come at a price. While these stronger amines are often needed to help solubilize other components in the formulation and adjust the pH to the desired range, their pKa value's boost the pH of the metalworking fluids, resulting in more aluminum staining and residues."

Potnis discusses specific amines that have been found to minimize aluminum staining. He says, "3-Amino-4-octanol (3A40) and 2-amino-1-butanol/2-amino-2-ethylpropanediol (AB/AEPD) can be beneficial. These chemistries are effective at high pH values with (AB/AEPD promoting better neutralization efficiency. The performance of these alkanolamines alone, as well as in combination with other amines, has been studied extensively and performance benefits have been seen on widely used aluminum alloys such as 356, 2024, 6061 and 7075."

**Screening tests**

All respondents indicate that the best approach for evaluating staining is to immerse aluminum metal coupons in a specific fluid. Harwood says, "Typical tests are done on the diluted fluid (at working concentration, e.g. 5%) and a series of aluminum alloys are immersed in the fluids for a period of time. Once removed, the coupons are evaluated for change in appearance and also weight gain or loss compared to the test coupon. Sandwich tests are also conducted in some aerospace approvals. These procedures are more focused on galvanic corrosion."


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Figure 1 shows an example of the type of testing Harwood believes needs to be done. A 60% oil containing emulsifiable oil is evaluated at a 5% concentration for three hours at 55 C with the four aluminum and one copper alloys listed. The emulsifiable oil is formulated with (pH 9.2) and without a phosphate ester (pH 9.3). Inclusion of the phosphate ester in the formulation led to the elimination of staining in all five alloys tested.

Cole's approach is to soak aluminum panels in 20 dH (approximately 350 ppm) hard water in a MWF diluted to a concentration between 3% and 5%. She says, "Be sure the coupon is halfway submerged to evaluate the vapor phase of the aluminum coupon. Enclose the container and place it in a 50 C oven overnight (18 hours). In the morning, observe the staining/corrosion/pitting (*see Figure 2*). Be sure to include two controls of 100% deionized water and 100% of the 350 ppm hard water without any metalworking fluid. Please keep in mind that this is a very harsh test."

For evaluation of Filiform corrosion, Cole advises that standards can be obtained from ASTM D2803 (Standard Guide for Testing Filiform Corrosion Resistance of Organic Coatings on Metal)[2].

Minch says, "The most common way to quickly screen the efficacy of a corrosion inhibitor is simply by fully or partially immersing a single metal coupon of the desired alloy in the test fluids and allowing it to sit at room temperature for 24 to 48 hours. The severity of the test can be increased by elevating the temperature to 40 C or 50 C. Upon removal from the fluid, the coupon can be visually inspected for staining. Both the immersed portion and the portion of the coupon above the fluid may be of interest (if only partially immersed). Ideally, the metal surface will be free of black or brown oxidation stains. Coupons are often monitored for weight loss or gain. Screening tests come in a variety of forms, but the best test is always the one that most closely emulates the conditions that the metal and fluid experience in the field."

Figure 3 shows the results from an immersion test for seven pairs of aluminum coupons immersed in a MWF at a pH of 9.2. The difference in the composition of the metalworking fluid is those coupons immersed in a fluid containing a phosphorus-based corrosion inhibitor are on the left, while results from coupons immersed in the same fluid without the corrosion inhibitor are on the right.

**STAINING EXAMPLE – Typical Metalworking Test Fluid 5% Emulsion 3hours @ 55°C**

| Product | Cu W004A | Al 2014 | Al 5754 | AL 6061 | Al 7075 |
|---|---|---|---|---|---|
| No Phosphate Ester |  |  |  |  |  |
| With Phosphate Ester 1000 ppm in emulsion |  |  |  |  |  |

Figure 1. **Evaluation of four aluminum and one copper alloys in a 60% oil containing emulsifiable oil are shown. Results from testing with (bottom row) and without (top row) a phosphate ester show the importance of using this additive to minimize staining.** *(Figure courtesy of Italmatch SC, LLC.)*

Figure 2. **Staining/corrosion/pitting is observed from aluminum coupons soaked in metalworking fluid diluted to between 3% and 5% in 20 dh (approximately 350 ppm) hard water at 50 C for 18 hours.** *(Figure courtesy of Clariant.)*

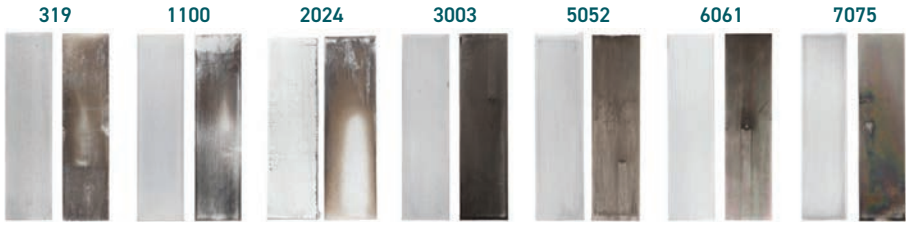


Figure 3. **Seven pairs of aluminum coupons were fully immersed and evaluated in a metalworking fluid at a pH of 9.2. The coupon on the left was immersed in a fluid containing a phosphorus-based corrosion inhibitor while the right coupon was immersed in the same fluid without the corrosion inhibitor.** *(Figure courtesy of The Lubrizol Corp.)*

Potnis feels that both liquid and vapor phase aluminum staining performance should be conducted at a minimum in varying degrees of water hardness/chloride levels. He says, "Ideally, the formulation also should be evaluated for microbial performance if this is a fluid that will be recirculated or has potential for microbial contamination. Of course, the emulsion must also be stable and other performance attributes such as cast-iron corrosion, must also meet necessary specifications."

Phosphate free formulations containing a triazine biocide were evaluated at a pH of 10 in coupon testing with 6061 Aluminum.

The evaluation was performed on metalworking fluids diluted to 5% in 200 ppm water hardness. The fluids were prepared with different amines (*see caption for Figure 4 for identification of the amines*). Top and bottom results shown in Figure 4 differed due to the addition of 1% 3A40 for the bottom set of results.

Chen recommends two types of screening tests. He says, "An aluminum stain inhibitor should be evaluated for weight loss from a coupon test which is a chemical test. Electrochemical techniques such as polarization and electrochemical impedance spectroscopy also should be used."

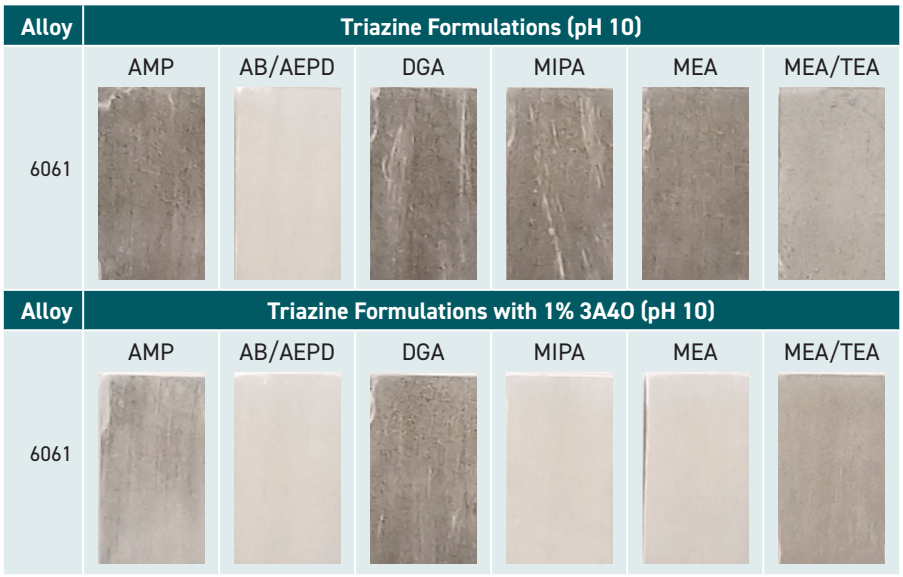


Figure 4. **Phosphate free MWF formulations containing a triazine biocide were evaluated at a pH of 10 in coupon testing at a 5% dilution in 200 ppm water hardness. Fluids were tested in the following amines: AMP (2-amino-2-methyl-1-propanol), AB/AEPD (2-amino-1-butanol/2-amino-2-ethylpropanediol), DGA (diglycolamine), MIPA (monoisopropanolamine), MEA (monoethanolamine) and MEA/TEA (monoethanolamine/triethanolamine). Coupons on the bottom were immersed in fluids that also contained 3A40 (3-amino-4-octanol).** *(Figure courtesy of ANGUS Chemical Co.)*

**Differentiate performance**

Minch believes the best way to differentiate the performance of an aluminum stain inhibitor is to work with a model fluid formulation. He says, "Inhibitors should be used at the same percent active in the model formulation, and the level of staining observed should be compared on immersed coupons. The formulation that provides the least amount of staining (assuming no weight loss occurred) without negatively impacting other fluid performance parameters is the best inhibitor. Again, trying to match conditions and metallurgy to the actual expected field conditions are the key to success."

Cole recommends two strategies for differentiating the performance of individual aluminum stain inhibitors. She says, "Performance of potential inhibitors should be compared against two controls (deionized water and hard water) as well as a formulated fluid that does not contain added corrosion protection (just triethanolamine [TEA] and monoethanolamine [MEA]). Consideration should be given to examining galvanic corrosion by potentially managing the cast iron chip test and separating the metals afterwards to see if any weight loss occurred on the aluminum chips."

**Formulator's perspective**

Two representatives from MWF formulators were asked for their perspective on aluminum stain inhibitors and whether the current options are satisfactory or is there need for better alternatives.

STLE-member Jennifer Lunn, senior chemist at JTM Products Inc. in Solon, Ohio, says, "There are several great options for aluminum stain inhibitors that exist in the market today. These options even play a dual role when formulating; they provide not only protection of the aluminum, but also contribute to the extreme pressure performance of the fluid, lowering formulation complexity. Until phosphate ester chemistry is regulated in MWFs, these really are a great choice when needed."

STLE-member Kevin Saunderson, director of technology at New Age Chemical in Delafield, Wis., says, "Overall, I have found the currently available additives, when used in water-based MWFs, effective in protecting a majority of the aluminum alloys used by our customers from staining. The number of available options, their relative ease of use and reasonable cost have made this performance aspect easily attainable."

When asked about amines, Saunderson indicates that they are a necessary evil in formulating water-based MWFs and machining aluminum alloys. He says, "However, the amines commonly chosen by MWF formulators offer far too many benefits to be ignored and can still be used effectively on a wide variety of aluminum alloys in use today. The challenge involves properly balancing the desire for excess alkalinity (buffering capacity) which can benefit product longevity, with the desire for aluminum compatibility. While all amines contribute to aluminum staining to a certain degree, how the amine is neutralized is almost as critical as the choice of amine. Proper selection of the acid-functional component can significantly improve compatibility of the in-use fluid with aluminum while potentially reducing the need for costly inhibitors."

Lunn says, "The tried and true amines work and are cost effective in their traditional functions. But supplementary additives often need to be added to counteract the negative impact they might have on performance, such as aluminum staining. Some of the new amine chemistries available to the market currently have shown the ability to reduce aluminum staining and also have a dual purpose which can assist with lowering formulation complexity."

Saunderson welcomes better amine options to deal with aluminum staining. He says, "The current amines have been and will continue to be used successfully by MWF formulators. However, there will always be interest in new or better whether it involves a new molecule or a new synergy with an existing amine." ▶

Lunn recognizes that the increasing use of aluminum in applications such as automobiles will mean that "aluminum friendly" amines and aluminum stain inhibitors will continue to be important additives for the MWF formulator. She says, "As more aluminum is incorporated into a vehicle's makeup, metalworking fluids will need to be adapted to account for their growing use."

Saunderson feels that alternative chemistries for aluminum stain inhibition already exist. He says, "The challenge could involve rebalancing existing formulas to accommodate the change in additive chemistry followed by extensive testing to validate equal or better performance. Depending on the number of formulas and the overall scope of the change, this could take significant time. With the uncertainty around the potential regulatory timeline, it makes sense to have a plan in place sooner rather than later."

There is concern that the use of phosphorus compounds may now be restricted in MWFs because they are considered as the root cause for algae bloom formation. This may lead to increasing challenges for formulators in minimizing aluminum staining.[3] Lunn says, "With the increased accumulation of phosphates in the environment, it is possible they will come under scrutiny in metalworking fluids. If that happens, specialty amines will play a very important role in formulating 'aluminum friendly' fluids."

**Future trends**

Chen predicts there will be greater demand for aluminum stain inhibitors. He adds, "Inhibitors of higher effectiveness are needed with a preference for organic based inhibitors."

Potnis believes there will be more focus on aluminum stain prevention in formulations via multifunctional additives rather than specific inhibitors. He says, "This market is developing a greater understanding of aluminum staining and how specific chemistries, such as phosphate esters and acid-amine salts, can create concerns as well as innovative solutions. For example, utilizing chemistries such as 3A4O and AB/AEPD to address multiple performance attributes (e.g., fluid longevity, aluminum staining, cast iron corrosion, pH stability, etc.) allows potential regulatory and cost savings benefits on top of performance."

## How the amine is neutralized is almost as critical as the choice of amine.

Minch focuses on the increasing use of aluminum in the automotive industry. He says, "One of the more certain trends regarding aluminum stain inhibitors is their expected growth relative to increasing aluminum consumption in some markets. Automotive is one major market where aluminum stain inhibitors may see significant growth. Steel and aluminum comprise the majority of materials within today's automobiles and are expected to continue that leadership position for years to come. One of the main drivers for aluminum usage is its lightweight properties, which has been one major pathway for OEMs to achieve higher government-mandated mileage and emission standards. In fact, SME recently noted that 200,000 tons of aluminum capacity will 'come on line' early next year for the automotive market; the implication is that this volume will be used for structural and body components.[4]"

With the automotive industry forecasting that electric vehicles (EVs) will replace internal combustion engine automobiles over time, Minch predicts that lightweighting will continue to be a concern for the EV market. He says, "Aluminum is expected to be a solution for these vehicles as well. Aluminum Insider expects that EV aluminum demand will be near 825,000 mt in 2019 and may grow ten-fold by 2030. Applications for this aluminum usage include sheet, extrusion, battery components and even EV charging stations.[5] Mitigating corrosion in EVs is especially of concern, both of which must be protected to ensure good performance.[6]

Minch concludes by stating that the trend to diversify materials used to produce automobiles beyond just steel and aluminum will lead to a growing need for more effective corrosion/stain inhibitors. He says, "Such diversification of materials can potentially cause galvanic corrosion issues where metals such as aluminum reside. As long as this is practiced, corrosion inhibition practices will need to be fully investigated to ensure that vehicles meet their lengthy corrosion performance requirements.[6]"

Cole believes the need for better corrosion protection in general will lead to the development of packages that will inhibit aluminum and ferrous corrosion. She also indicates that many of these products will exhibit multifunctional characteristics.

Another trend to facilitate the use of aluminum in automotive applications is known as vacuum impregnation. Cole says, "This technique is not necessarily an inhibition technology but rather an approach to facilitate the movement of molten aluminum via vacuum delivery into a mold to 'impregnate' the voids and pores in a cast part by eliminating points of entry from potential penetration from electrolytes."

Harwood says, "Demand for aluminum stain inhibitors is growing because of the use of certain aluminum grades (such as the 7000 series) that are being more widely used in the aerospace and automotive sectors. These grades are more susceptible to corrosion/staining."

Inhibitors for preventing staining of aluminum alloys have become a very important additive for the metalworking fluid formulator. Proper selection of these inhibitors in combination with amines will be necessary now and in the future as a more diverse number of materials will be used in such applications as automobiles.

*Neil Canter heads his own consulting company, Chemical Solutions, in Willow Grove, Pa. You can reach him at* ***neilcanter@comcast.net****.*

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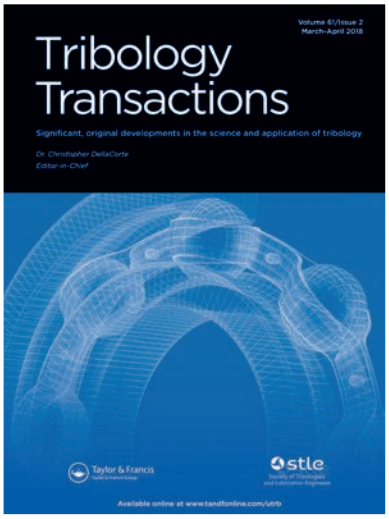


## TRIBOLOGY TRANSACTIONS

All papers selected by Christopher DellaCorte.

**Life Model Enhancement for Hybrid Ball Bearings**
Pradeep K. Gupta and Erwin V. Zaretsky
Tribology Transactions, 2019, Volume 62, Issue 6, pp. 1129-1141

Based on experimental life data on silicon nitride balls, the stress-life exponent and life constant in the generalized ball life equation, developed earlier, are modified to better simulate the fatigue life of silicon nitride balls in hybrid ball bearings. The modified ball life equation is then integrated with generalized life equations for the outer and inner races to model the life of a complete hybrid ball bearing. It is found that in view of the relatively high stress-life exponent for silicon nitride balls, computation of hybrid bearing life with infinite ball life may not be unreasonable. Model predictions are in good agreement with limited available experimental life data on hybrid ball bearings.

**The Synergistic Effect of Cr and CrFe Particles on the Braking Behavior of Cu-Based Powder Metallurgy Brake Pads**
Peng Zhang, Lin Zhang, Dongbin Wei, Peifang Wu, Jingwu Cao, Cairang Shijia, Xuanhui Qu and Kangxi Fu
Tribology Transactions, 2019, Volume 62, Issue 6, pp. 1072-1085

Different Cu-based brake pads applied in high-speed railway trains were fabricated by the co-addition of Cr and CrFe particles, and the influence of the Cr/CrFe ratio on the tribological behavior of the powder metallurgy brake pads were studied by a reduced scale testing apparatus with the pad-on-disc configuration under various braking speeds. The results indicated that the Cu-based brake pad containing 6 wt% Cr and 4 wt% CrFe exhibited the highest and the most stable friction coefficient as well as the lowest wear loss when the braking speed was higher than 300 km/h. Moreover, a new reasonable explanation is provided for the effect of Cr and CrFe particles during the braking process. The excellent braking properties are attributed to the synergistic effect of Cr and CrFe on promoting the formation and stabilization of a tribofilm. Cr particles, which have high reactivity with Fe and O, act as a steady source of fine oxides in the tribofilm, and CrFe particles bear the load and strengthen the subsurface in the position near the friction surface. It is clear that the application of an appropriate ratio between Cr and CrFe can develop Cu-based brake pads suitable for more serious braking conditions.

**An Alternative Procedure to Quantify Soot in Engine Oil by Ultraviolet-Visible Spectroscopy**
Vicente Macián, Bernardo Tormos, Santiago Ruiz and Antonio García-Barberá
Tribology Transactions, 2019, Volume 62, Issue 6, pp. 1063-1071

Due to new pollutant emissions standards, internal combustion engines need several emission control strategies (and related procedures) such as exhaust gas recirculation, diesel/gasoline particulate filters and selective catalyst reduction that allow them to comply with complete requirements defined on those standards. These strategies result in faster degradation of engine oil, one of the most relevant consequences of which is an increase in soot contamination level. All of these strategies facilitate soot generation. Consequently, soot is one of the most important contaminants present in engine oil. The main technique to measure the content of soot in oil is thermogravimetric analysis (TGA), but this technique has certain limitations. TGA requires a long and specific procedure and has limitations in measuring small concentrations of soot in oil. Therefore, the design of an alternative technique to quantify soot in oil is relevant. One alternative is Fourier transform infrared (FTIR) spectroscopy, but it also has limitations related to low concentrations of soot in oil. This work presents an alternative technique based on ultraviolet-visible (UV-Vis) spectroscopy that allows quantification of small soot contents in used engine oil samples and avoids potential interference from other typical contaminants or those related to measurement processes, such as sample cuvette material.

**Tribological Performance Improvement of Polyamide against Steel Using Polymer Coating**
Kian Bashandeh, Pixiang Lan and Andreas A. Polycarpou
Tribology Transactions, 2019, Volume 62, Issue 6, pp. 1051-1062

Polyamide (PA) is used in industrial applications such as automotive, gears, bearings and pipeline spacers. As a bearing material, PA can support high-contact pressures un-

der low sliding speeds. To achieve high-performing and durable contacts, it is necessary to have low friction, low vibration and low wear between PA and steel contacts at different operating temperatures. This study proposes the use of an advanced polymer coating, namely, aromatic thermosetting copolyester (ATSP), on the steel surface and investigates the friction and wear properties between PA–ATSP coating and PA–steel at environmental temperatures of 25, 50 and 80C. The experiments were carried out using a pin-on-disc configuration under unlubricated sliding conditions. The results showed excellent performance of the coating on reducing the coefficient of friction (COF) by 80% and PA wear by 95% compared to bare steel. The ATSP coating worked as a predeposited transfer layer and showed nonmeasurable wear under moderate to high contact pressure conditions at all temperatures. The worn surfaces and the formation of transfer layers were further examined using scanning electron microscopy and energy-dispersive X-ray spectroscopy.

**Fabrication, Characterization, and Evaluation of Monolithic NiTi Nanolaminate Coatings**
Nicole Cameron and Zoheir Farhat
Tribology Transactions, 2019, Volume 62, Issue 6, pp. 1007-1018

Nickel and titanium are common elements in coatings. When Ni and Ti are combined they offer promising characteristics, specifically the NiTi intermetallic phase. NiTi is a shape memory alloy possessing a stress-induced reversible martensitic transformation. NiTi alloys are used in a variety of industrial applications and are prevalent in the automotive, aerospace and medical sectors. The problem with using NiTi is its poor machinability and formability. Applying NiTi as a surface coating will provide an alternate manufacturing method that will require limited machining. The objective of this study is to produce a superelastic NiTi surface coating that still possesses excellent wear and dent resistance while reducing forming and machining processes. A full and comprehensive understanding of the formation of the superelastic NiTi phase during coating development is nonexistent. Fabrication of this intermetallic phase is

formed through the annealing of sputter-deposited Ti and Ni layers in a coating. Crystalline phases and residual stresses of the coating were established through X-ray diffraction (XRD). The behavior of the coatings was studied through scratch and Hertzian-type indentation testing. XRD and residual stress analysis suggest that intermetallic Ni and Ti phases precipitated at elevated temperatures, which resulted in excellent dent and scratch resistance compared to as-deposited Ni/Ti nanolaminate coating. This indicates that superelastic NiTi can form while annealing nanolaminates, further suggesting that dent- and wear-resistant coatings have the potential to be produced through annealing layers of Ni and Ti to form superelastic NiTi.


## TRIBOLOGY LETTERS

**Correlation Between the Adsorption and the Nanotribological Performance of Fatty Acid-Based Organic Friction Modifiers on Stainless Steel**
Z. Zachariah, P. C. Nalam, A. Ravindra, A. Raju, A. Mohanlal, K. Wang, R. V. Castillo and R. M. Espinosa-Marzal
Tribology Letters, 2020, Volume 68, Issue 1, Article 11
Selected by Nicholas D. Spencer

Friction modifiers are generally amphiphilic molecules, whose effectiveness depends on a number of parameters including their architecture, their binding strength to the tribological surface and their solution behavior. Zacharaiah et al. have used a combination of light-scattering methods, quartz-crystal microbalance with dissipation and lateral force microscopy to establish that the crucial issue is the rate of adsorption from solution. This was found to correlate well with the ability to lower friction and is influenced by the degree of unsaturation in the alkyl chains, the propensity to form large micelles in oil solution and the size of the binding head group.

**Brittle or Ductile? Abrasive Wear of Polyacrylamide Hydrogels Reveals Load-Dependent Wear Mechanisms**
S.Z. Bonyadi and A.C. Dunn
Tribology Letters, 2020, Volume 68, Issue 1, Article 16
Selected by Juliette Cayer-Barrioz

The behavior of hydrogels is intensively investigated in terms of mechanical properties, friction and lubrication mechanisms. In this paper, the authors focused on the wear behavior of polyacrylamide hydrogels against a rough probe. The wear mechanisms were identified using surface analysis, dissipated energy and stress analysis. This confirmed that complex wear modes take place, leading to a competition between ductile and brittle fracture. The cartography built and presented in this paper suggests that the transition between the two regimes is governed by a critical load rather than the speed (in the range tested).

**Perfluoroalkoxy (PFA)–Alumina Composites: Effect of Environment on Tribological Performance**
M. A. Sidebottom, C. A. Atkinson, K. L. Campbell, T. F. Babuska, C. P. Junk, H. E. Burch and B. A. Krick
Tribology Letters, 2020, Volume 68, Issue 1, Article 14
Selected by David Burris

Perfluoroalkoxy polymer (PFA) is a cousin of PTFE, the main difference being that PFA contains a few wt.% of perfluoroalkyl vinyl ether, which enables the polymer (unlike PTFE) to be melt processed—a significant advantage for fabricating materials. Like PTFE, pure PFA has poor wear properties under high pressure, but these can be improved by orders of magnitude by the judicious use of fillers. Sidebottom et al., using infrared spectroscopy as well as tribological characterization, have examined the role of humidity in the wear behavior of PFA–alumina composites and found that, like the corresponding PFA–alumina materials that they had previously investigated, the new materials also form smooth transfer films in humid environments that impart low friction and low wear properties to the material. However, under both dry and water-submerged conditions, the wear becomes severe. This behavior can be attributed to the formation of carboxylate species on the PFA in the presence of water vapor, which enables stronger bonding to the alumina filler, more effective transfer-film formation and a more wear-resistant surface.

**Relating Tribological Performance and Tribofilm Formation to the Adsorption Strength of Surface-Active Precursors**
A. M. Khan, H. Wu, Q. Ma, Y.-W. Chung and Q. J. Wang
Tribology Letters, 2020, Volume 68, Issue 1, Article 6
Selected by Ashlie Martini

The formation of carbon tribofilms in situ has been previously shown to be a mechanism by which additives can improve friction and wear performance. This is thought to proceed by mechanochemical reactions. Khan et al. explored how the adsorption properties of additives influence their effectiveness in participating in such reactions by comparing the behavior of three additives, cyclopropanecarboxylic acid (CPCa), cyclopropanemethanol (CPMA) and 1-cyclopropylethanol (CPEA), which contain either –COOH and –OH as surface-active groups, but all contain the metastable 3-membered cyclopropane ring. Tribological results show that the -COOH-containing additive (CPCa) was the most effective at reducing friction and wear, and Raman spectroscopy showed it was the only one to produce C-containing tribofilms. Molecular dynamic simulations and thermogravimetry showed that, of the three additives, it was CPCa that bonded the most strongly to a model iron oxide surface, suggesting that strong adsorption is an important initial step to "hold the molecule in place" prior to the mechanochemical reactions that lead to the crucial tribofilm formation.

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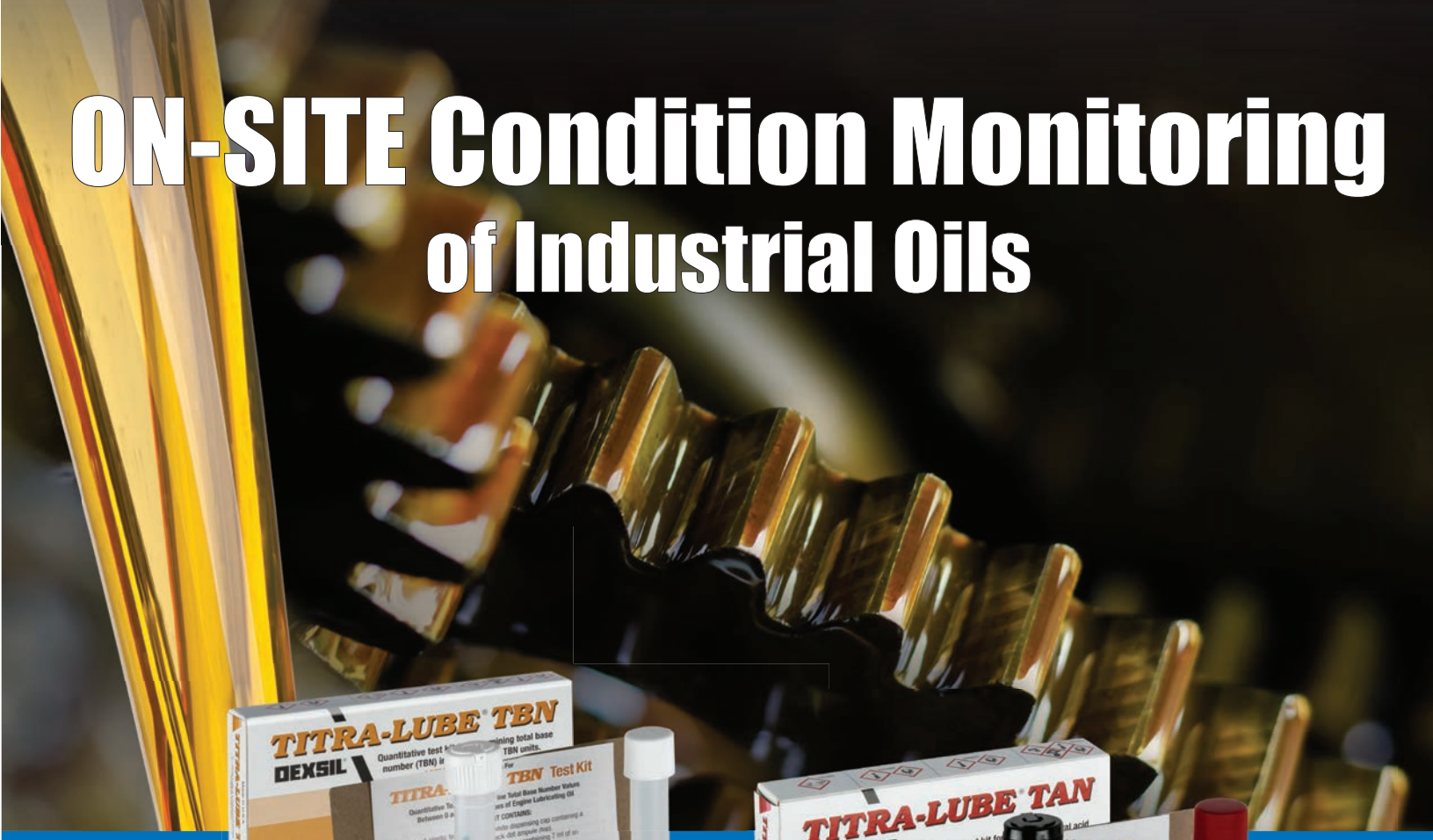


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## TOP STORIES

### Shell Lubricants acquires American Chemical Technologies

**Pennzoil-Quaker State Company dba SOPUS Products**, a subsidiary of Shell Oil Co., which comprises Shell's U.S. lubricants business, has purchased the assets of American Chemical Technologies, Inc. (ACT), which manufactures and distributes industrial fluids based on core glycol chemistries. The purchase includes ACT's intellectual property, customer contacts and technology/product pipeline, as well as its two manufacturing facilities in Fowlerville, Mich., and Bowling Green, Ky.

"We are very excited about this acquisition, which enables Shell Lubricants to expand our product offering to industrial customers, especially those in the primary metals and power sectors," says Carlos Maurer, SOPUS Products president. "The resilient B2B industry sector is a key pillar in Shell Lubricants growth strategy, and ACT's portfolio of fire-resistant fluids, unique industrial lubricants and environmentally acceptable lubricants ideally complements our existing U.S. industrial lubricants portfolio."

STLE-member Kevin Kovanda, ACT president and co-owner, says, "This is a momentous day for American Chemical Technologies. Our dad would be very proud to know that his vision of industrial selling, unprecedented customer service and hard work would attract the interest of Shell Oil. Our experience over the past 40-plus years of introducing new synthetic fluid technologies into the industrial lubricant marketplace brings a host of fluid chemistries that will blend perfectly into Shell's global lubricant portfolio."

While the acquisition of assets is effective immediately, SOPUS Products has contracted with ACT to continue to operate the business on SOPUS Products' behalf for a transitional period.

### Klüber Lubrication to acquire TRAXIT International

Munich, Germany-based, **Klüber Lubrication München SE & Co. KG** has purchased the Schwelm, Germany-based, TRAXIT International GmbH. The purchase agreement includes all assets of the company including the international subsidiaries. With this acquisition, TRAXIT Group becomes a division of the Klüber Lubrication Group.

TRAXIT provides the wire drawing industry with a complete range of lubricants to suit all types of wire for all applications for 139 years. It has grown to be one of the largest wire-drawing lubricant producers in the world. TRAXIT runs manufacturing sites in Germany, China, and the U.S. with lubricants sold throughout the world. The company has subsidiaries, agents or representatives present in more than 150 countries and employs some 150 people globally.

"We have been pursuing an active acquisition strategy for many years with a view to expanding the existing businesses by further value-added services. High-end products and services for the manufacturing of wires are a perfect addition to our existing portfolio of advanced specialty lubricants improving operational efficiency and protecting customer assets," says Claus Langgartner, speaker of the board, Klüber Lubrication. "TRAXIT fits in very well at Klüber Lubrication as similar success factors and mechanisms to the markets of our existing businesses apply."

### ADM and P2 Science sign commercial-opportunities MOU

**ADM** and **P2 Science, Inc.**, have signed a memorandum of understanding (MOU) that intends to build on both companies' expertise in the field of chemistry and renewable materials derived from plants. The MOU proposes the companies will work together in the development of commercial opportunities for plant-based monomers, polymers and ingredients for personal care and flavors and fragrances.

ADM has a leading global portfolio of plant-based feedstocks including carbohydrates, vegetable oils and terpenes. P2 has developed a suite of patented green chemistry process technologies that convert renewable feedstocks into high-value specialty chemicals. P2 also has a growing portfolio of novel aroma chemicals and cosmetics ingredients. Under the terms of the MOU, the companies will bring these and other strengths together with the aim of developing business opportunities in the growing market for plant-based, renewable chemicals and materials. The initial program targets will include monomers for polyesters and polyamides and other chemical intermediates derived from vegetable oil feedstocks.

"We are very happy to be working with ADM in such an important area. ADM's global presence in agricultural feedstocks is unparalleled. Their market reach and technology are second to none, and we couldn't think of a better partner to be working with in the emerging bioeconomy," says Neil Burns, CEO of P2 Science.

### Ascend Performance Materials expands Alabama plant

**Ascend Performance Materials' Decatur facility is one of only four plants in the world that produce ADN on a large scale.** *(Photo courtesy of Ascend Performance Materials)*

Houston-based **Ascend Performance Materials** has finalized plans of a $175 million project to expand production capacity at its Decatur, Ala., manufacturing facility. The funds will go toward constructing energy co-generation units that will help improve power efficiency and heat recovery at the chemical processing location.

The site currently employs more than 400 people with the expansion bringing in more than 150 new jobs by the time it's fully functional. The co-generation units will reduce emissions by an estimated 60%. The expansion, in part, stems from the unique work performed on site, as it's one of only four facilities in the world that produces adiponitrile (ADN) on a large scale. AND is a critical ingredient used in the production of nylon 6,6, a high-performance plastic used in applications ranging from vehicle airbags to high-voltage electrical connectors.

Construction is slated to begin this spring, with a completion target of late 2021.

## PROMOTIONS & TRANSITIONS

### Hoon Kim named director of technology at Nanotech Industrial Solutions

Hoon Kim

**Nanotech Industrial Solutions Corp.** appoints **Hoon Kim** the company's director of technology at its headquarters in Avenel, N.J. Kim is well known in the lubricants, coatings and polymer industries.

Kim brings more than 25 years of experience in value-added chemical product markets. Prior to joining Nanotech, he worked at Chemetall-BASF as senior principal scientist where he managed new technology and product development for lubricants and coatings. He led technical innovation groups (both local and global) for surface chemistry/polymer technology. He has also initiated, coordinated and completed the Global Metalworking Training Program. In addition, he was responsible for developing high-performance anti-staining chlorine-free, boron-free, bio-stable semisynthetic metalworking fluids, as well as phosphorous-free anti-stain/corrosion technology.

His previous professional experience also includes roles as a senior polymer chemist at Thermo Fisher Scientific, senior scientist at Amyris, and research scientist at The Lubrizol Corp.

Kim earned his doctorate in polymer science at the University of Akron, and has a master's of science degree in chemistry and polymer science from Inha University, Inchon, South Korea, and the University of Akron, respectively.

## IN MEMORIAM

### Duncan Dowson 1928-2020

Duncan Dowson

British engineer **Duncan Dowson**, often referred to as the father of tribology, passed away on Jan. 6. His work is credited with revolutionizing the approach to and understanding of the science, and his seminal work enhanced understanding and spawned new developments and designs in areas as diverse as rotating machinery, internal combustion engines and biotribology, particularly natural and artificial human joints.

Dowson was appointed professor of engineering fluid mechanics and tribology at the University of Leeds in 1966. He served as pro-vice chancellor and head of Mechanical Engineering at Leeds, retiring in 1993. He was president of the Institution of Mechanical Engineers in 1992.

Dowson was elected to the Fellowship of Engineering in 1982 and appointed a Fellow of the Royal Society in 1987. He worked on committees established by the Department of Education and Science, the Department of Health and Social Security, and the Science and Engineering Research Council. Along with H. Peter Jost, Dowson was an instrumental member of the Ministry of Education and Science committee that identified tribology in 1966.

After his retirement, Dowson remained at Leeds as emeritus professor. He held many awards for his work, including the 1979 Tribology Gold Medal and seven honorary degrees. At Leeds, he helped to found the Bio-Engineering Group for the Study of Human Joints and the now annual Leeds-Lyon Symposium on Tribology. He had published 600 papers and five books, and served as former editor of several engineering journals.

Dowson was born in 1928 and attended Leeds University, where he was awarded a bachelor's of science degree in Mechanical Engineering in 1950 and a doctorate in 1952.

He began his career as a Research Engineer at Sir W.G. Armstrong Whitworth Aircraft Co., where he remained for two years before taking up the position of Lecturer in Mechanical Engineering at Leeds University. The following year he established the Institute of Tribology at Leeds to coordinate tribological practice in industry, teaching and research. He served as institute director until 1987.

At Leeds University, Dowson promoted innovative degree courses, undergraduate exchange systems and continuing professional education. His research focused on elastohydrodynamic lubrication, the lubrication of machine elements and natural synovial joints, and the tribological characteristics of total replacement joints.

## Raymond Louis Thibault 1941-2020

**Raymond L. Thibault**, a 30-year STLE member and volunteer, passed away Jan. 6.

**Raymond Louis Thibault**

Thibault's post-secondary education was at the University of New Hampshire where he obtained a bachelor's degree in chemistry in 1963. He attended Harvard University, achieved his MAT designation in 1964 and subsequently taught chemistry for two years at Manhassett High School in Long Island, N.Y. Ray concluded his postgraduate studies at the University of Wisconsin with a master's of science degree in organic chemistry in 1968 and an MBA in 1970.

Thibault began his business career in 1970 when he joined Enjay Chemical, a subsidiary of the Esso Chemical Co. (which later became Exxon Chemical). During his 31-year career with Exxon, he traveled the world and held many positions within sales management and marketing before retiring in 2001.

After retiring, Thibault formed Lubrication Training and Consulting, which specialized in helping individuals involved in the lubricants field prepare for STLE's Certified Lubricant Specialist (CLS) designation. He helped hundreds of students during this time.

At its 2019 Annual Meeting in Nashville, STLE announced the establishment of the Raymond L. Thibault Excellence in Education Award to honor STLE members who serve as teachers and mentors to those learning the practical aspects of tribology and lubrication engineering. The award will be presented for the first time at STLE's May 3-7 Annual Meeting & Exhibition in Chicago.

In announcing the scholarship, STLE Immediate Past President Greg Croce said, "For decades Ray has served our industry as an extraordinary teacher, writer and speaker on the practical aspects of tribology and lubrication engineering. During that time, he worked tirelessly to promote STLE's mission of advancing the practice of tribology and has distinguished himself as a leading teacher in the practical aspects of lubrication engineering."

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**Des-Case Varnish Removal System**
(Photo courtesy of Des-Case Corp.)

**Chevron Delo 600 ADF**
(Photo courtesy of Chevron Products Co.)

## Heavy-duty engine oil

**Chevron Products Co.**, a division of Chevron USA Inc., maker of technologically advanced engine oils, lubricants and coolants, introduces **Delo 600 ADF**, a new heavy-duty engine oil that delivers maximum system protection to both engine and emissions system. Heavy-duty engine oils are formulated up to the API CK-4 limit of 1% sulfated ash. Chevron's Delo 600 ADF is formulated to 0.4% sulfated ash, which helps drastically reduce the rate of diesel particulate filter (DPF) clogging, to deliver extended DPF service life and industry redefining fuel economy retention that helps contribute to reducing customer operating costs. Available in SAE 15W-40 and SAE 10W-30 viscosity grades.

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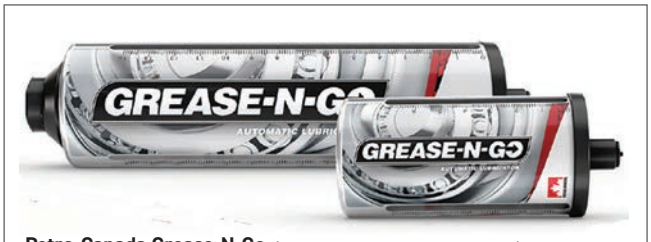

**Petro-Canada Grease-N-Go** (Photo courtesy of Petro-Canada Lubricants.)

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# Predictive maintenance

**Executive Summary**

*The best news from this month's survey came from readers suggesting that, after decades as lower-priority items, condition monitoring and predictive maintenance are getting more attention from senior management. Survey respondents say managers in greater numbers are understanding the high price of equipment failures and the cost of process interruptions. "It was less important 30 years ago, now it's viewed as an absolute necessity," said one survey respondent. Readers add that artificial intelligence (AI), online real-time sensors and the Internet of Things (IoT) are expanding their roles in condition monitoring, as they generate results faster and reduce the need for full-scale labs. But there is still room to grow for most end-users as these technologies continue to be incorporated into the condition monitoring process. Said one respondent: "There's potential, especially with AI, but the promise is way off of where reality is right now."*

# Q.1

## Describe the most significant change in condition monitoring and predictive maintenance you've seen during the past year.

Advances in identifying the metallurgy of individual particles in oil, not just overall concentrations.

The use of high-speed cameras to show vibration.

Artificial intelligence.

Acoustic monitoring of engines.

In-line/real-time monitoring sophistication has improved.

Commercially affordable design and implementation of real-time scanning electron microscopy in particle size determination and analysis.

The testing of incoming product cleanliness was conveyed by a customer; this is where the condition monitoring truly starts!

Online submission of data which, in turn, speeds the results turnaround by >50%. We hear much about enhanced testing and equipment, but human involvement is still required.

AI used to predict failures.

It has become a requirement for many of our customers to attend training.

Thermal tools to predict wear are more in use.

Remote health monitoring and real-time oil analysis sensors.

Condition monitoring using online real-time monitoring (IoT) using the CMMS as an interface to raise request for values going out of setpoints.

The increasing use of portable and in-line measuring devices in equipment and the increase in knowledge in the culture of lubrication and reliability maintenance professionals.

Software-based AI involvement. New and sophisticated instruments for precise testing.

Sensors are getting smaller and cheaper. As more sensors become wireless and "stick-on" and inter-connected, we will see a great improvement in equipment reliability.

| Which is the most important goal of predictive maintenance? | |
|---|---|
| Improve equipment availability | 54% |
| Reduce maintenance cost | 46% |

*Based on responses sent to 15,000 TLT readers.*

It is not limited to the past year that the availability and affordability of sensors and handheld devices seems to be accelerating. Yet, using those consistently for predictive maintenance is lagging.

Companies that we deal with have taken a more proactive view during the past year. For many of them, this is a new initiative. They have learned the hard way that just reacting can actually cost more money. One company had a machine that was critical to its success. Management waited years to address it and got into a situation where the machine was close to failure. They contracted to have the fluid changed and the PM work done to the tune of $250,000. Had they reacted sooner, the cost would have been way less.

The automation and categorization (barcoding systems) that have taken the place of time-consuming data entry.

Ultrasound is becoming more common.

More companies are starting to switch to these methods over the traditional time or routine-based maintenance.

Online constant monitoring of lubricant quality through cell towers.

Vibration monitoring on all types of rotating equipment which is now more cost effective due to reduced cost design.

The use of ultrasonic sensors in parallel to lubricate the friction nodes of devices.

The use of AI diagnostics for the incorporation of all machine health data (oil analysis, vibration, telematics, sensors) into a single integrated platform.

Used oil analysis to analyze the break-in course for equipment. Monitoring of low-speed equipment using oil analysis.

Need to align with OEMs for diesel/natural gas engines for minimum/maximum wear metals for alerts.

The connection between simple condition monitoring by local sensors/devices goes further to a connected network of sensors in a machine and a cloud system in the background (IoT shapes more and more).

Merging of service companies.

The most significant change in condition monitoring and predictive maintenance I have witnessed or heard about during the past year is that more companies are realizing the true value of these methodologies in increasing equipment uptime and availability.

# Q.2 Please describe roadblocks preventing the use of predictive maintenance.

Budget restrictions not allowing for either the personnel to shepherd a program or for the tools/training to properly run a program.

Management's lack of understanding of the cost of failures and the cost of process interruptions.

Time and lack of interest.

Too many sources of conflicting guidance on limiting values.

Budget constraints (short sightedness!).

The (perceived) high initial cost.

The thought in industry that still supports the lack of validity in condition monitoring is the biggest roadblock.

Personnel and allocating the time to process samples timely and accurately.

Funding and outage durations to allow device installations. The culture attitude of, "We haven't had it for 100 years and haven't needed it."

Older maintenance supervisors not wanting to accept change and use new procedures.

No space for mounting control sensors, unconscious of inexperienced designers to predict space for such sensors, low susceptibility of new devices to predictive maintenance.

The cost of CMS on wind turbines (my industry) is completely out of line with the actual savings offered. I've never seen a product that I projected to have a positive ROI for my company.

Depending on the process, they start from the investment planning of portable or online devices when new equipment is to be purchased, then buy them as limited as possible to have less investment cost.

The high cost of updating the equipment and adapting cutting-edge technology. Sometimes they prefer to work with the essentials.

In general, the high cost of access to available technology.

Software interfaces.

People turnover.

| Who is best qualified to conduct preventive maintenance and interpret the results? | |
|---|---|
| Independent third-party service companies | 16% |
| Internal staff | 61% |
| Equipment OEM | 24% |
| Embedded component/equipment software | 29% |
| Component vendors | 16% |

*Based on responses sent to 15,000 TLT readers. Total exceeds 100% because respondents were allowed to choose more than one answer.*

Reluctance to spend the money and time to retro fit. It is criminal for instance, that there are so few wind turbines that are fully instrumented with appropriate sensors to gather condition information. A wind turbine tech should be able to monitor the performance of bearings and gears, etc., from the ground before climbing the tower.

Maybe the largest roadblock is baseline data that accounts for the location, environment, user, and duty-cycle so as to minimize false alerts and the frustration and inefficiencies that go along with false alerts.

Lost local knowledge in end-users themselves.

New equipment takes time to build a trend, and predictions cannot be made until that time. Another roadblock with older equipment is that, in some cases, a baseline is not present to compare with the used. This results in inaccurate data and untrustworthy predictions.

Costs, availability of the technology, awareness, training and willingness of the staff and data security are some of the challenges in implementing and use of a reliable predictive maintenance.

Myopic equipment managers not wanting to spend money unless equipment is broken.

Overcoming the lack of lubrication knowledge or stigmas around lubrication. For example, I must change the oil in my car every 3,000 miles because the car light/sensor tells me to.

Management resistance to spending capital and breaking old habits.

OEM alignment. Sometimes difficult to align in terms of technologies—differences in goals and targets.

Being able to schedule enough equipment down time to perform the needed maintenance.

Lack of understanding of the fundamentals of predictive maintenance.

Lack of management of predictive maintenance programs.

Cost.

Customer resistance to change maintenance practices. Lack of understanding of failure to properly maintain systems on the part of customers.

You have to have a mindset whereby you have to be diligent with it and maintain good records.

In the classes I hold at various companies, I always see the weakness of lubricant knowledge among organizational managers and personnel. Not paying attention to the depth of the problems.

False actions/alerts. Predictive maintenance is still not precise enough to predict remaining life time of a system/component/tool or bearing. In new machines, the accuracy seems to be better. In older machines, the censoring is often not sufficient to make proper prediction for the system.

Machine guards.

For old equipment, one of the roadblocks is communication with old data systems.

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- 2D Materials - Materials Tribology and Nanotribology Joint Session
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- Condition Monitoring
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- Environmentally Friendly Fluids
- Fluid Film Bearings
- Gears
- Grease
- Lubrication Fundamentals
- Materials Tribology *(including Solid Lubricants)*
- Metalworking Fluids
- Nanotribology
- Nonferrous Metals
- Power Generation
- Rolling Element Bearings
- Seals
- Surface Engineering *(including Hard Coatings)*
- Synthetic and Hydraulic Lubricants
- Testing in Soft Tribology - Tribotesting and Biotribology Joint Session
- Tribochemistry - Materials Tribology and Nanotribology Joint Session
- Tribology of Biomaterials - Biotribology and Materials Joint Session
- Tribotesting
- Wear
- Wind Turbine Tribology.



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# Q.3 Please describe the impact of the Internet of Things and artificial intelligence on condition monitoring and predictive maintenance.

Still low. It's kind of like selling a Rolls Royce to someone who doesn't know how to drive and has a budget of $1,000.

It makes information transfer better, but its misuse tends to bury people with data that may or may not be of value.

Lessening the need for full-scale labs.

Big increase in interconnectedness readily allows both Big Data and microdata analysis!

Broad implementation of real-time monitoring and failure prediction due to reduction in prices.

Extremely powerful in noticing and highlighting the influence of the minute details and aid in proper diagnosis.

The internet has boosted the knowledge of people needing to find possible similar issues with equipment.

Increasing the speed and amounts of transmitted signals—the drawback of frequent training for operators of equipment due to the rapidly changing software and hardware configurations.

There's potential, especially with AI, but the promise is way off of where reality is right now.

Measures details and we are able to stream real-time data as the equipment is running in a remote location.

They help document and refine the technical information data for analysis.

Huge impact. Data processing is in a new era. Advance pattern recognition and data modelling have changed the philosophy of conventional predictive maintenance.

We are just scratching the surface with the use of IoT and AI for condition monitoring and predictive maintenance. However, as sensors (vibration, temperature, etc.) become smaller, cheaper and wireless, we will see the benefit of AI to handle more and more condition monitoring information and format it into real actionable intelligence.

In the future, this information could even be used by the OEM to improve the reliability of even individual components in machines.

IoT and AI have great potential to improve condition monitoring and predictive maintenance and its benefit for reducing unscheduled interruptions and minimizing downtime. But in many (most?) situations, insufficient knowledge exists regarding all the potential failure modes and range of operating conditions, leading to false alerts.

With the companies we deal with, this is still something that is out of reach.

IoT and AI have expedited the processes involved in predictive maintenance. Results are obtainable much faster.

IoT and AI are crucial for the condition monitoring and predictive maintenance connecting the equipment on the cloud. The potential expenses as well as data and equipment security challenges should, therefore, be of major consideration.

The internet has good information, but many forums are the blind leading the blind with bad misinformation.

It is helping to bring awareness to people who truly want to know/understand more.

Potential for faster response and increased data analysis to drive more efficient operations, particularly on a large fleet.

It is huge and is what has brought down the cost to implement.

Earlier detection of incipient failures has significant impact on lead times to failure and allows for proper planning and scheduling. The P on the P-F curve is detected earlier than any physical CM methods such as vibration monitoring and oil analysis via sampling. This results in significant savings in the mining industry. There is also a significant reduction in safety risk as the human-machine interface is reduced.

AI for machine learning models has allowed for more data to be considered when diagnosing machine faults.

More information can be found on the internet these days so condition monitoring information is more readily available.

Unfortunately, at present our company does not pay much attention to IoT.

AI can help increase a remaining lifetime in a specific machine due to machine learning capability. This can close the gap between traditional life time calculations and real failure modes in a specific machine, which has its own boundary conditions. Usually you don't know all parameters in a system you need to make a realistic life time prediction. AI/machine learning does not need this detail. It just learns out of the given system step by step.

I believe it will have a monumental impact on condition monitoring and predictive maintenance. This is why some have coined the term the 4th Industrial Revolution. In a world where everything seems to keep getting faster, these will definitely be a game changer. In the past, it may have taken weeks or even months before an underlying fault condition manifested itself. However, now we are looking at minutes and hours.

***Editor's Note:*** *Sounding Board is based on an informal poll of 15,000 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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**April**
Ad close: Feb. 20
Materials: Feb. 27
*(STLE Pre-Annual Meeting issue! Bonus Distribution: ILMA 2020 Engage Spring Conference, April 2-4, Asheville, N.C.)*

- Oil Analysis
- Bearings
- Gear Lubrication
- Environmentally Friendly Fluids
- Base Stocks
- Automotive Tribology

**May**
Ad close: March 23
Materials: March 30
(75th Anniversary Commemorative issue! Salute STLE by placing a special, congratulatory ad where your logo takes center stage! Bonus Distribution: STLE 2020 Annual Meeting & Exhibition, May 3-7, Chicago, Ill.)

- Gears
- Engine & Drivetrain
- Automotive Tribology
- Solid Lubricants

**June**
Ad close: April 30
Materials: May 7
(Post-convention issue! Bonus Distribution: NLGI, June 14-17, Miami, Fla.)

- Additives
- Bearings
- Oil Analysis
- Grease
- Solid Lubricants
- Automotive Tribology

**July**
Ad close: May 22
Materials: May 29

- Oil Analysis
- Bearings
- Base Stocks
- Environmentally Friendly Fluids
- Engine & Drivetrain

Mark Your Calendar!

# 2020 STLE Tribology Frontiers Conference

Cleveland Marriott Downtown at Key Tower
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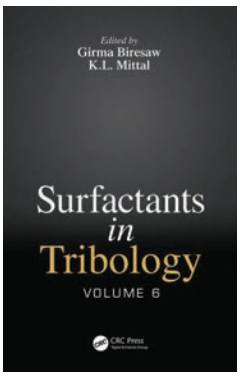
## Technical Books

### Surfactants in Tribology, Volume 6

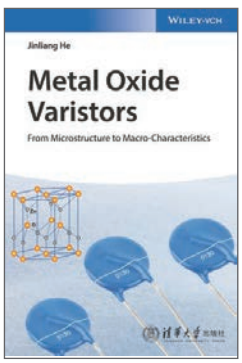
**Editors: Girma Biresaw and K.L. Mittal**
*Publisher: CRC Press*




Surfactants play a critical role in tribology, controlling friction, wear and lubricant properties such as emulsification, demulsification, bioresistance, oxidation resistance, rust prevention and corrosion resistance. This is a critical topic for new materials and devices, particularly those built at the nanoscale. This new volume addresses important advances, methods and the use of novel materials to reduce friction and wear. Scientists from industrial research and development organizations and academic research teams in Asia, Europe, the Middle East and North America will participate in the work. Available at **www.crcpress.com**. List Price: $199.95 (USD), hardcover.

### Metal Oxide Varistors: From Microstructure to Macro-Characteristics

**Author: Jinliang He**
*Publisher: Wiley*




Completely up to date, this is the first comprehensive monograph on metal oxide varistors with a focus on microstructure, conduction mechanisms, device failures, ageing, additive impacts and future varistor systems. It covers the fundamentals and applications of metal oxide varistors, including their macro-characteristics, microstructural properties and the device-internal physical and electrical mechanisms. The author reflects on the achievements made in varistor research and proposes new approaches to analyze and predict the macro-characteristics, employing such methods as micro-contact measurements and numerical simulations. He also looks at future directions for varistor research. Available at **www.wiley.com**. List Price: $215.00 (USD), hardcover.

## STLE Local Section Meeting Calendar

Events listed here are local section programs. For further details and a full listing of other upcoming section events in your area, visit **www.stle.org**. Meeting announcements can be sent to TLT Magazine, Attn: Rachel Fowler, **rfowler@stle.org**.

### March

**STLE Houston Section Education Course:** March 11, Sasol North America, 12120 Wickchester Ln., Houston, Texas. For more information, visit **stlehouston.com/2HoustonSTLE/index.shtml**.

**STLE Canton Section Education Seminar:** March 11, 9 a.m. to 6 p.m., Courtyard by Marriott Canton, 375 Metro Cir NW, North Canton, OH. For more information, visit **www.stlecanton.org**.

**STLE Chicago Section:** Topic and speaker TBD, March 19, 5:15 p.m. (hospitality hour), 6:15 p.m. (dinner), 7:15 p.m. (speaker presentation), Ashton Place, 341 75th St., Willowbrook, Ill. Contact: Patrick Brutto, **patrick.e.brutto@gmail.com**, or register at **www.chicagostle.org**.

### April

**STLE Canton & Cleveland Section Joint Meeting:** Topic TBD (Speaker: STLE President Mike Duncan, Daubert Chemical Co.), April 7, 7 to 9 p.m., Courtyard by Marriott Canton, 375 Metro Cir NW, North Canton, OH. For more information, visit **www.stlecanton.org**.

**STLE Virginia Section:** Topic and Speaker TBD, April 15, 6:30 to 8 p.m., Legend Brewing Co., 321 W. 7th St., Richmond, Va.

**STLE Chicago Section:** Topic and speaker TBD, April 16, 5:15 p.m. (hospitality hour), 6:15 p.m. (dinner), 7:15 p.m. (speaker presentation), Ashton Place, 341 75th St., Willowbrook, Ill. Contact: Patrick Brutto, **patrick.e.brutto@gmail.com**, or register at **www.chicagostle.org**.

**STLE Houston Section:** Topic TBD plus Commercial Innovation Forum (Speaker: STLE President Mike Duncan, Daubert Chemical Co.), April 17, 11 a.m. to 1 p.m., Maggiano's Little Italy, 2019 Post Oak Blvd., Houston, Texas. For more information, visit **stlehouston.com/2HoustonSTLE/index.shtml**.

## STLE Certification Exams

STLE is offering numerous certification exams in the coming months. Here is the information on each exam:

- March 13 from 8 to 11 a.m. at the Hampton Inn Dallas-Irving-Las Colinas, 820 W. Walnut Hill Ln., Irving, Texas.
- April 3 at the Inntel Hotels Amsterdam, Provincialeweg 102, 1506 MD Zaandam, Netherlands.

For the online registration form, go to **www.stle.org**; click on the professional development tab at the top. Then go to certification, then registration. Online registration closes two weeks prior to the exam date. Onsite registration may be available on a first come, first serve basis. For more information and for other methods of registering, you may contact STLE Headquarters at (847) 825-5536 or email **certification@stle.org**.



## Industry Conferences

### The 12th International Fluid Power Conference

The 12th International Conference on Fluid Power (IFK) is March 9-11 in Dresden, Germany, The IFK is one of the world's most significant scientific conferences on fluid power control technology and systems. It will be devoted to discuss topics with the theme Fluid Power—Future Technology! For more than 20 years, the exhibition has provided an excellent meeting point for professional exchange between scientists, users and manufacturers on an international level. It offers a unique opportunity to network with a large number of experts from the fluid power branch and to find out more about innovative products and system solutions. For more information, visit **www.ifk2020.com**.

### Contact Mechanics International Symposium 2020

The Contact Mechanics International Symposium (CMIS) 2020 is May 13-15 at the Hotel Prealpina in Chexbres, Switzerland, CMIS started from the desire to gather researchers interested in a broad range of topics in theoretical, computational and experimental contact mechanics. The 10th edition of CMIS pursues this tradition of interdisciplinary research and fosters intense discussions and exchanges by assembling a group of leading researchers in a pristine location. During these three days, discussions will involve a wide panorama of topics in the area of contact mechanics, with the objective to reinforce interactions and collaborations between the various communities. For more information, visit **https://cmis2020.epfl.ch/**.

### 8th International Symposium on Surfactants in Tribology

The 8th International Symposium on Surfactants in Tribology is held in conjunction with The 23rd International Symposium on Surfactants in Solution (SIS-2020). The symposium is June 26-July 1 at Maria Curie-Skłodowska University in Lublin, Poland. The organizers of this event are STLE-members Girma Biresaw and Kash Mittal.

Surfactants perform a wide range of functions in tribology, including basic lubrication functions such as control of friction and wear as well as controlling a wide range of lubricant properties. Examples of lubricant properties that can be modified with the application of surfactants include emulsification/demulsification, bioresistance, oxidation resistance, rust/corrosion prevention, etc. Surfactants also spontaneously form a wide range of organized assemblies in polar and non-polar solvents.

There is little information on the subject of surfactants and tribology together, and this symposium is tasked with filling the gap. You are invited to submit your abstract and participate at **www.sis2020.umcs.eu**. Oral and poster presentations are welcome. Direct questions to Girma Biresaw at **girma.biresaw@usda.gov**. Be sure to select the Surfactants in Tribology track when submitting your abstract.

# Do you report to a bad boss?

*Strategies to understand your situation and seek a positive resolution—when possible.*

**By Ken Pelczarski**

**Has your productivity**, motivation and overall job satisfaction been affected by a bad boss? Is your boss driving you crazy virtually every day on the job? How do you deal with the situation? Should you leave the company and how soon?

The answers to these questions are a matter of personal judgement. I will try to provide answers in this article that will increase your chances of making the best career decision for yourself when you have a bad boss. For convenience, I will refer to the boss as a male even though bad bosses come in all shapes, sizes and genders.

Your boss can turn a great job at a top employer into a truly miserable experience. That is why many industry surveys indicate that having a bad boss is the top reason for leaving a company.

Unfortunately, finding a great boss can be extremely difficult. One big reason is that employees are frequently promoted simply because they have done a great job. Employers often do not consider the fact that different skills are required to be a leader vs. an individual contributor. In these cases, individuals have risen to their level of incompetence, the so-called Peter Principle.

**What actions can you take when you have a boss you cannot tolerate much longer?**

- Begin to document incidents regarding issues with your boss.
- Gather support from other subordinates with the same issues.
- Attempt to work things out directly with your boss.
- Go above your boss to resolve issues through higher level management.
- Request a transfer to a different department or location.
- Stay with the company and adapt to your boss' management style (if issues are not too serious).
- Leave the company. If your career growth is being affected, issues with your boss are not short term and positive internal changes are not likely.

**Factors that influence the actions you take:**

- Does your boss report to a higher-level manager? You might be reporting to the top person in the company and need to work things out directly with him.
- How much clout do you have with top management? You may be able to go above your boss easily without negative ramifications.
- Does top management have a high opinion of your boss? If they do, you may be hurting yourself by complaining about your boss.
- How passionate are you about your employer and current role? It may not be worth the effort to affect internal changes if you can attain better career growth by switching jobs.
- Do other subordinates of your boss have the same opinion of him? If so, you may rally a small group of co-workers to join you in confronting your boss or higher-level management.
- How much does your boss care about his job and the company? If your boss values his job, he may have incentive to work things out with you.
- Is your boss likely to stay with the company long-term? Perhaps you should stick around if you have insight that your boss is about to leave or be dismissed.

## Bad bosses

Below are some of the most common types of bad bosses and how you can deal with them:

**1. The Micro-Manager**

This is probably the most common and well-recognized type of bad boss. A micro-manager imposes unnecessary oversight on his subordinates. This management style may impact your productivity through involvement with excessive paperwork and other reporting measures. If micro-management is pervasive throughout upper management, you will be challenged with trying to change the culture of the organization. If your boss is the sole micro-manager, you need to stress to him that you thrive with lesser rules and more freedom. Ask him to give you a chance to demonstrate how much you can accomplish in this kind of work environment. Express that this approach will free him up to spend time on other tasks.

**2. The Yes Man**

Does your boss always side with upper management? Does he fail to back you when his superiors question your efforts or performance even when he knows you are a strong performer? This will inevitably make you look like (a.) a less desirable employee, (b.) you are unsuitable for a promotion, and/or (c.) a candidate to be let go from the company. You need to have candid conversations with your boss to convince him that he will look better in the eyes of upper management if he backs you when you are doing a great job.

**3. The Deserter**

Does your boss fail to support you and his entire team by not offering encouragement and a positive attitude? Does he fail to promote your best ideas to his superiors? Your motivation, productivity, and overall job satisfaction could suffer as a result of his lack of support. Emphasize that your performance will be even better with his increased support and that you will equally support his efforts.

**4. The Hermit**

Does your boss seem to be hiding when communication with his subordinates is critical? Projects may not stay on track and time may be wasted without consistent communication between the boss and his team. Emphasize to your boss that mutual feedback is important for maximum work efficiency by his team and that these communications will enable him to do his job more effectively.

**5. The Unclear Communicator**

Does your boss attempt to communicate with you but the intended message is often not received? Without clear communications, tasks are misunderstood, time is wasted and less is accomplished. Work out a system of communication directly with your boss. Repeat messages back to him to ensure everything was heard correctly. Also, have these messages put clearly in writing to the satisfaction of both parties.

**6. The Non-Visionary**

Does your boss fail to rally his team around a mission and/or high-end goal? This may cause team members to be less motivated and go through the motions instead of working hard collectively toward an exciting end goal. Talk to your boss about how much it means to you to be excited about a project and to understand the purpose behind your efforts.

**7. The Small Picture Viewer**

Does your boss tend to nitpick and be focused on details all the time? He could be a perfectionist and be losing sight of the forest for the trees. Stress to your boss that what you especially need from him is consistent project status updates. Tell him that you will be able to manage your time and be more successful on projects with this information, and that too much focus on details can get in the way of the bigger picture.

**8. The Praise Withholder**

A basic intrinsic need of most people is recognition. When receiving regular appreciation, most employees will work harder as a result. Your boss may not even be aware that he is withholding his appreciation. Encourage your boss to recognize above average effort and performance. Tell him that you will also accept suggestions for improvement.

**9. The Daily Critic**

Does your boss focus on the negative and constantly criticize you? Too much criticism can decrease the level of team performance. On the other hand, small doses of constructive criticism can improve team performance. Have an open conversation with your boss about the right mix of praise and criticism that you believe will optimize your level of performance.

**10. The Time Bomb**

Do you have a boss who is always ready to explode at any time? Does he exhibit volatile and unpredictable behavior? This management style will cause team members to be constantly on edge and overly careful of making mistakes instead of potentially achieving success through trial and error. Come to an agreement directly with your boss that will result in him responding in a calm manner when he is upset. If he cannot learn to control his own behavior, talk to upper management about options including anger management classes for your boss.

**11. The Credit Thief**

Is your boss always taking credit for your ideas and successes? This could easily cause your performance to be undervalued by upper management. Document your accomplishments for discussion with your boss and perhaps with his superiors if he does not agree to give you written credit. Encourage a collaborative effort in which you and your boss get shared credit when appropriate. Pick your battles carefully by confronting situations promptly that only involve significant achievements.

**12. The Slave Driver**

Does your boss overwhelm with you tasks that you cannot possibly finish on time? This will likely decrease morale and may trigger you to rush through tasks and make critical mistakes. Arrange a meeting with your boss to explain that you are behind on projects. Document how your time is being spent so you are not viewed as a slow worker.

**13. The Do-It-Yourselfer**

Does your boss have a problem with delegating tasks? He likely believes that he can do things better himself. As a result, he is not trusting or empowering his subordinates. Talk to your boss about delegating a select project to you that he would normally not delegate. Work hard to show him how successful you can be with such a challenging project. Stress to him that he will have more time to focus on other things if he delegates more projects.

**14. The Maverick**
Does your boss appear to be out for himself without caring for others or properly following company rules and guidelines? It is a large problem when a manager is not aiming for team accomplishments. You and other team members need to build a closer relationship with your boss in order to facilitate mutual caring and trust. Arrange to spend time outside the office with the boss, perhaps doing one of his favorite activities.

**15. The Know-It-All**
Does your boss like to show off his knowledge? Does he rarely ask for your input and have a my way or the highway attitude? By doing this, he is depriving himself of valuable input and ideas from his team. Meet with him and start by complimenting him on his tremendous knowledge. Tell your boss how much you have learned from him. At the same time, express your belief that you have a lot to offer and encourage him to give your best ideas a try.

**16. The Slacker**
Is your boss a low bar setter who does not expect much from his team? Low expectations will certainly lead to low levels of performance. Team members will have little pride in their work. Their jobs may even be in jeopardy due to sub-par performance. Talk to the boss about your desire to work hard towards bigger goals. Offer to take charge of projects. Perhaps he is coasting to retirement and will welcome your offer.

**17. The Status Quo Maintainer**
Does your boss seem to be afraid of change? Does he frequently resist new ideas? This approach may seriously stifle a team's innovation and overall success as well as cause the company to fall behind its competition. Talk to your boss about experimenting with new ideas, perhaps one new idea at a time, that will likely result in new successes and high recognition from his superiors.

**18. The Bean Counter**
Do you find that your boss is evaluating you strictly by numbers? There is nothing wrong with quantification as a performance measure to determine level of success. However, your boss will often miss on recognizing superior performance if he focuses only on numbers. Have a discussion with your boss about implementing other qualitative measures of performance such as (a.) project progress, (b.) research discoveries, (c.) new customer leads and (d.) relationship building with prospective customers.

**19. The Paranoid Threat Monitor**
Does your boss constantly look over his shoulder? Does he seem insecure and threatened that somebody will make him look bad or even steal his job? Assure him regularly that one of your main goals is to have him and the team both do well. If your boss is doing a good job, enhance your relationship with him by giving him favorable reviews to his superiors.

**20. The Shady Operator**
Have you discovered that your boss is conducting unethical business practices? This will ultimately affect your employer's reputation and perhaps yours as well. Meet with your boss to discuss the origin of these shady dealings. If he tells you that upper management condones these practices, confirm this directly at these higher levels and proceed to leave the company to protect your reputation. If he tells you that he is doing this alone, arrange a meeting with upper management and aim for an immediate end to these practices.

**21. The Saboteur**
It is a highly concerning situation when your boss sabotages your good work. Your job could easily be in jeopardy in the short term. Meet with your boss to make sure there is not a good reason for what is happening. If there is no immediate resolution, bring documentation of sabotage to a meeting with upper management. Encourage the corrective action of dismissal of your boss. It is recommended that you leave the company if there is no action taken (ideally the firing of your boss) that would guarantee against further sabotage.

There are different degrees of boss toxicity and many lethal combinations of bad boss traits. Some issues are deeply rooted while others can be attributed to a new boss who is simply misguided in the best way to manage his team.

Many good bosses have mild tendencies toward managing in manners described above. These tendencies are normally easy to deal with in the course of the boss-subordinate relationship. Bad bosses, however, employ more extreme leadership methods in one or more of the above categories of management styles. Issues with bad bosses need to be addressed promptly and could lead to you leaving the company if corrective action is not taken.

You will likely have little or no influence when a new boss is selected to work above you at your current employer. When you are interviewing with a prospective new employer, however, you will be able to choose whether you want to work for the boss at that company. Be sure to learn as much as possible in the interview process about the management style of your potential boss and the entire management team.

I have been my own boss for 35 years and feel fortunate not to have any headaches about bosses. On the flip side, it can be difficult to maintain self-discipline and be tough on yourself when necessary. A great boss helps with these issues and has a positive effect on your morale and motivation. Strive to work for a boss that will facilitate your career growth and bring out the best in you for maximum productivity and success.

*Ken Pelczarski is owner and founder of Pelichem Associates, a Chicago-area search firm established in 1985 and specializing in the lubricants industry. You can reach Ken at 630-960-1940 or at* ***pelichem@aol.com****.*

# CALL FOR STUDENT POSTERS

Photos courtesy of Dr. Robert Erck.

## 2020 STLE ANNUAL MEETING & EXHIBITION

**THE SOCIETY OF TRIBOLOGISTS AND LUBRICATION ENGINEERS** is seeking student posters for its 75th Annual Meeting & Exhibition at the Hyatt Regency Chicago in Chicago, Illinois (USA), May 3-7, 2020.

Event organizers are inviting students from all areas of tribology research to participate in a special session dedicated to student posters. 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 **https://stle2020.abstractcentral.com.** The deadline for abstract submissions is **March 2, 2020.** 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 2019-2020 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 2019-2020 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 4, 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 5.

For additional questions about the student poster session, please contact Merle Hedland, **mhedland@stle.org.**

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# Sharks and friction

## *Using basic principles of tribology, sharks rank among nature's fastest swimmers.*

**By R. David Whitby**

**As most swimmers** will tell you, it is much easier to walk than it is to swim. This is because of the density of water compared to air. But why is it that sharks are able to swim so fast? Sharks need to be able to swim very fast in order to catch their fish prey.

The shape of a shark's body is one reason for their ability to swim fast. Most sharks, like dolphins, tuna, swordfish and porpoises, have streamlined, torpedo-shaped bodies that allow them to swim through the water with a low amount of friction. Most bottom-dwelling sharks have flattened bodies that let them hide in the sand on the ocean bed. These slower-swimming sharks usually hide on the ocean floor and burst out of the sand to surprise their prey.

Streamlining allows a shark to swim with less physical exertion. Since an animal never really knows what its energy reserves are and when they are going to be needed, it is always wise to prepare for a possible scarcity by using energy efficiently. Fast-swimming predators (such as great white, Mako, tiger and hammerhead sharks) have tails with lobes that are almost the same size. Slower swimming sharks have tails that are more asymmetrical. Thresher sharks have tails where the top lobe is up to half their body length.

Swimming style and body form are intimately linked. Lamnid sharks (great white, Mako, tiger and similar sharks) combine a solidly built, torpedo-shaped body, a narrow tail stalk supported by lateral keels and a crescent moon-shaped caudal fin. Unlike the graceful, nearly whole-bodied swimming stroke used by a typical whaler shark, the lamnids swim in a relatively stiff-bodied fashion. Each swim stroke involves arching the body laterally into a shallow curve, with the amplitude increasing from very small, at the head and anterior two-thirds of the body, to large at the posterior edge of the caudal fin. By oscillating the body from side-to-side in this fashion, tremendous swimming speeds can be achieved with remarkable energy economy. Rapid movement of the tail enables these sharks to accelerate very quickly.

**Slower-swimming sharks have asymmetrical tails with a top lobe nearly half their length.**

The other factor that allows sharks to swim faster than their prey is the surface of their skin. Shark skin is made of a matrix of tiny, hard, tooth-like structures called dermal denticles or placoid scales. These structures are shaped like curved, grooved teeth and make the skin a very tough armor with a texture like sandpaper. They have the same structure as a tooth with an outer layer of enamel, dentine and a central pulp cavity. Unlike the scales of bony fish (ctenoid scales) that get larger as the fish grows, placoid scales stay the same size. As the shark grows, it just grows more placoid scales.

All the spines of the placoid scales point backward (towards the tail), so it feels relatively smooth when you move your hand from head to tail but rough the other way. The scales are arranged in a mosaic pattern which surrounds the body of the shark like a helix and acts as a supportive corset. Because sharks have no skeletal bones, the muscles used for swimming are attached directly to the inside of this corset. This saves energy, allowing them to swim faster and further without tiring.

The scales also help the shark swim more quickly because their streamlined shapes help to decrease the friction of the water flowing along the shark's body by channelling it through grooves. They also aid in streamlining the shark while it glides through the water, as they reduce turbulence. This is done by directing the water through the grooves and thereby decreasing the friction of the water against which the body travels.

The skin of the shark has to be thick in order to assist it in retaining heat and supporting the muscles attached to its inner layers. The largest living shark, the whale shark, has skin that is about 10 centimetres (four inches) thick.

In general, sharks swim (or cruise) at an average speed of about eight kilometers per hour (five mph), but when feeding or attacking the average shark can reach speeds upward of 19 kilometers per hour (12 mph). Shortfin Mako sharks, the fastest shark and one of the fastest fish, can burst at speeds up to 50 kilometers per hour (31 mph).

*David Whitby is chief executive of Pathmaster Marketing Ltd. in Surrey, England. You can reach him at* ***pathmaster.marketing@yahoo.co.uk.***


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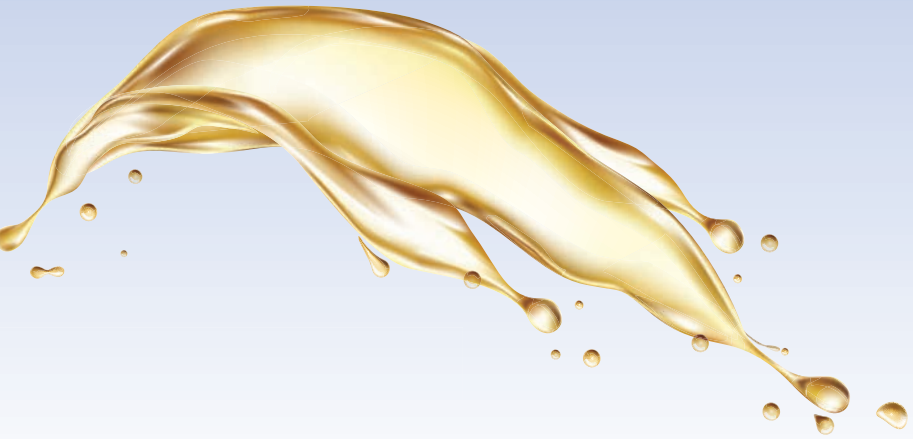

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