
TLT
TRIBOLOGY & LUBRICATION TECHNOLOGY
20 YEARS
of publishing excellence
SYSTEMS, STRATEGIES & RESEARCH FOR LUBRICATION PROFESSIONALS
AN stle PUBLICATION | OCTOBER 2023
The Possible End of PFAS
Time is running out to come up with replacement lubricants and associated products.
SPECIAL COMMEMORATIVE ISSUE
TLT celebrates two decades as the leading technical magazine serving the lubricants industry.
20
PLUS
Electric Vehicle Drivetrain Fluids
Test methods for evaluation
Rolling Contact Elements
Surface engineering and properties
Bearings
Types and applications
STLE UK Student Chapter
How it started and its future

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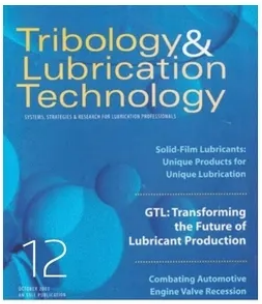

FEATURES

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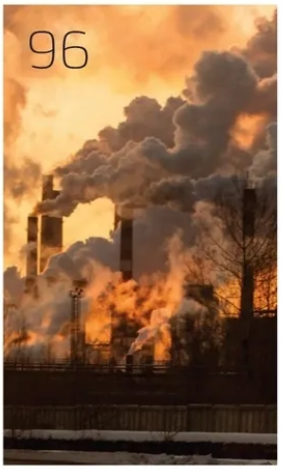

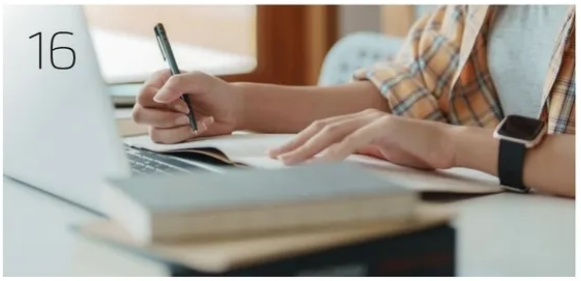

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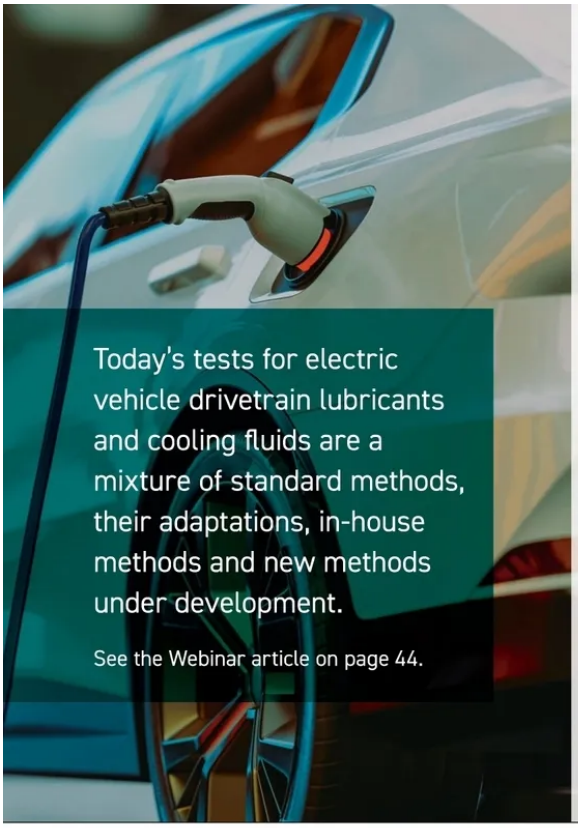

TRIBOLOGY & LUBRICATION TECHNOLOGY

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PUBLISHER'S PEN

20 years of excellence

TLT celebrates this important milestone by continuing to provide high-quality content.

By Rachel Fowler
TLT Publisher/ Editor-in-Chief

I've worked on TLT for almost nine years now, which is a small amount of time compared to TLT's entire existence. The first issue of TLT was October 2003—back then I didn't even know about the term *tribology*. Instead of TLT being a part of my life, it feels like I'm just a small part of its life.

To this day, when I explain to people what I do, I usually get asked, "What's tribology?" My favorite reaction from a new friend recently was complete silence for a few minutes. Then suddenly, she said, "I'll be honest—I don't know what that is, and I thought about pretending that I do." I've learned that tribology truly is everywhere in our daily lives, and I like sharing the topic with people who don't know about it. It's a fascinating topic that everyone should learn about.

Many STLE members see tribology in their everyday lives at home and at work in the industry. It's important to them, and they help make everything around us function. One of my favorite parts of the job is going to the STLE Annual Meeting and meeting those who have contributed to TLT. It's nice to talk to members in person and thank them for their hard work on TLT and with STLE.

It's still exciting seeing the next issue in my mailbox each month, knowing I had the opportunity to contribute to this incredible work. This wouldn't be possible without STLE members, great writers, TLT Technical Editors, the four TLT Editors who have helped run the magazine up to this point and the hardworking staff. Thank you for all of your support on this great publication. TLT wouldn't function without such great people.

> You can never stop learning about tribology and lubrication.

TLT was created 20 years ago to aid in the technical education and professional development of STLE members and industry colleagues. The article ideas come from STLE members and TLT Technical Editors who volunteer their time, knowledge and experience to help create this great content. I've had the privilege of editing feature articles, lubrication fundamentals, columns, interviews and more for nine years now, and I'm still learning something new in every issue. I can see why STLE members are interested in the subject. There are so many different topics to choose from: bearings, additives, grease, gears, metalworking fluids, automotive, wear, oil analysis—to name a few. You can never stop learning about tribology and lubrication.

It's been an honor and a privilege to work for TLT. And thank you to our readers who have stuck with TLT for 20 years. Here's to celebrating the 40th anniversary of TLT 20 years from now in 2043.

You can reach TLT publisher/ editor-in-chief Rachel Fowler at ***rfowler@stle.org****.*

Visionary society

There are many people within STLE who are making significant impacts on lubrication and tribology.

These members are critical components of STLE who provide direction, purpose and motivation for the field of lubrication and tribology.

By Dr. Hong Liang
STLE President

As a science and technical society, STLE consists of many members with vision. Here the vision refers to a clear and compelling image of the technical future for our community. Those members are critical components of STLE who provide direction, purpose and motivation for the field of lubrication and tribology. Their visions provide guidelines in decision making, creating common goals, inspiring commitment and influencing policy making. We are proud of who we are and what we do. In this article I'm using one example to support my statement.

One of many visionary figures in STLE is STLE Life Member Dr. Erwin V. Zaretsky. Zaretsky has been actively involved in STLE—he is a Fellow and chaired the Bearing Life Factors Committee for years. In 2021 he was inducted into the NASA Glenn Research Center Hall of Fame and selected based on "contributions having a sustained and far-reaching influence on the direction and mission of the center, whose work at the center has generated fundamental advancements in their field, and/or serve as an inspiration to employees through their character and embodiment of the NASA spirit." We all know that Zaretsky has made significant contributions in lubrication and

tribology, particularly in the aerospace industry. He played a pivotal role in advancing the understanding of lubrication principles, bearing design and reliability analysis. His work on rolling bearing fatigue has had a lasting impact on aerospace engineering and various other industries.

Zaretsky's research on lubricant properties, bearing fatigue life and lubrication-related failures have been well presented at STLE annual meetings and published, including books he authored and edited as STLE special publications. Zaretsky has about 200 publications that contributed to the fundamental knowledge of tribology. In his work, he emphasized combining theoretical understanding with practical application that helped bridging the gap between academic research and real-life problems.

Indeed, we have so many people within STLE who are making significant impacts on lubrication and tribology. Because of those visionary technical leaders, STLE leads our field with far-reaching vision. This past May, the STLE Board of Directors approved the 2023-2026 strategic plan (more information at **www.stle.org/StrategicPlan**). It lays out four focused domains in professional development, technology and innovation, communications and advocacy and organizational excellence. To succeed in the plan, each domain has a clear goal, objectives and key performance indicators.

Furthermore, STLE has recently released the 2023 Report on Emerging Issues and Trends in Tribology and Lubrication Engineering (more information at **www.stle.org/2023EmergingTrendsReport**). Led by Dr. Neil Canter, the Advance Innovation Team conducted research on exciting and new challenges and predicted future developments potentially impacting lubrication and tribology. We will see that the field of lubrication and tribology aims for a more sustainable and efficient future.

What is your vision for our fields?

Dr. Hong Liang is Oscar S. Wyatt Jr. Professor of the J. Mike Walker '66 Department of Mechanical Engineering at Texas A&M University in College Station, Texas. You can reach her at ***hliang@tamu.edu****.*

FROM THE EDITOR

We learn more in teams

There is a lot to learn from each other as each area has very unique issues and needs.

By Dr. Selim Erhan
TLT Editor

In my current job I am looking at applying chemistries that we have into application areas that may need them. The areas we cover are quite diverse—metalworking, grease, dust control, rubber, polymers, plastics, asphalt, oil fields, agriculture and the list goes on. Of course, there is a lot to learn as each area has very unique issues and needs.

Most people have worked at several different jobs and will be happy to contribute to a solution.

Fortunately the solutions are not always very complicated because at the molecular level, interactions are very precise. Carboxylic acids do not care if they are used in mining or metalworking fluids or personal care. They do what carboxylic acids do, and so do all the other molecules. It is very satisfying to balance these interactions to get the desired results. This journey is always useful even when a good outcome cannot be reached, because we always learn so much with every project. It is sad to see that so much information is lost, because most of the time we cannot attend multiple conferences, nor have time to read several publications from different areas.

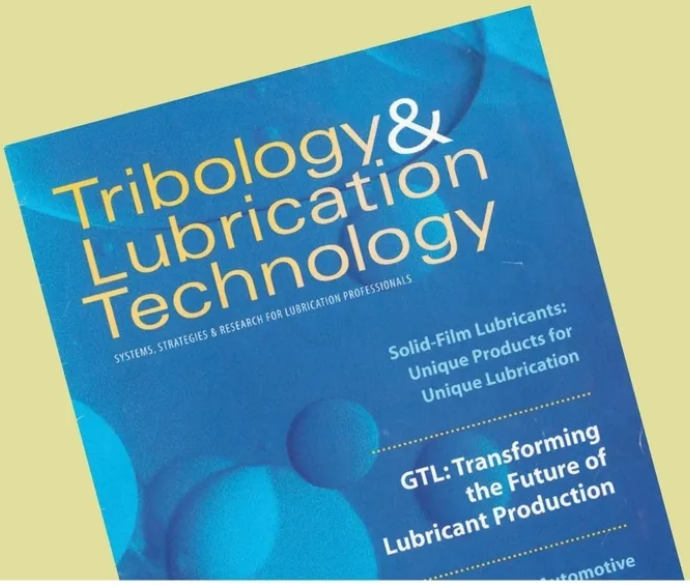
Even sometimes instruments that are developed in one area are perfectly suitable to be used in other areas. Surface interaction in dust control, mining and drilling are very similar to each other. A lubricant's behavior on drilling bits in oil fields is similar to its behavior on cutting tools in metalworking. Surface film thickness studies are useful for engine oil additives and greases. A fluid's internal friction in engine oils is similar to the turbulence of fluids during flow back in hydraulic fracturing. Surfactants that are used in downhole drilling that are heat stable also may be useful in high temperature applications in metalworking formulations. I would recommend looking at the websites of additive manufacturers. Most large companies list very diverse applications areas for their chemistries. If one finds that similar products can be used in different areas, it may be beneficial to look at the literature that comes out in those areas' magazines or conferences. The experience of people in these fields also can help solve our problems.

This search does not have to be solo. We could discuss experiences with other members of our teams. Most people have worked at several different jobs and will be happy to contribute to a solution. Another advantage of working in teams is that it enables us to keep a 360-degree view while moving a project forward. In the professional world where reasonable results are expected in reasonable times, one must strike a balance between the expected outcome, the cost, health and safety requirements, registration issues, the strength of the competition, the support from manufacturing and sales, logistic costs and even the political environment.

Being a chemist and dealing in the molecular world, one often gets lost in the excitement when the project starts—especially when it is moving forward as planned. This phase takes a long time, and if we do not surface once in a while and look where we are, we may get disappointed when one of the other branches cannot support the project. In my experience the best project management strategy is to start as a team from the very beginning. As soon as the idea appears, if a careful analysis of manufacturing, sales support, logistics, cost and competition are evaluated and the team is constructed with members of these branches, the team meetings become very productive. Team members not only help with their contributions but also remind others of upcoming problems or limitations. Another advantage is that the learning also is shared, and all team members benefit and grow even in unsuccessful attempts.

Dr. Selim Erhan is director of business development for Process Oils Inc. in Trout Valley, Ill. You can reach him at ***serhan@processoilsinc.com****.*

EDITORS' RETROSPECTIVE



TLT: At 20, no longer the adolescent

By Christopher DellaCorte
2003-2007

It ranks among the most respected monthly technical publications in our field and is distributed and enjoyed the world over.

As the founding editor of TLT, I played my part in its inception and launch. While it was an exciting time, it also was a bit nerve-wracking. Both publicly and privately I had my doubts that the shift from the monthly journal Lubrication Engineering to the more magazine-like format of TLT would have staying power. Serious hurdles had to be overcome. A major challenge would be the sourcing of timely, technically rigorous tribology relevant articles, month after month after month. I was nervous that the STLE staff and our string of writers would not have the stamina to keep TLT going for more than a year or two. It turned out that my concerns were overblown. The TLT team established a framework to collect topics of interest from members and visionaries in the field from which new articles emerged. This turned out to be a very effective content generation strategy.

Ten years ago, I gave a brief retrospective on TLT. At that time, TLT was no longer my own baby, as I had relinquished the lead position to new, fresh editors. At that time, I was serving on the STLE Board of Directors. Every quarter I had the chance to review reports on TLT and, like a proud uncle, I beamed. At 10 years old, TLT was growing up to become a pillar for the society alongside the education program and the annual meeting. More important, TLT was relevant and highly respected. A few years later, I moved from my STLE board position to lead STLE-affiliated journal Tribology Transactions as editor-in-chief. As a current member of STLE's Editorial & Publications (E&P) Committee, I again have the opportunity to check in with TLT on a regular basis. Just like an uncle attending family gatherings at the holidays each year, I have watched TLT grow up.

I am pleased to report, and I am sure you'll agree, TLT is no longer a child. It ranks among the most respected monthly technical publications in our field and is distributed and enjoyed the world over. TLT regularly includes tribology news and announcements, cutting-edge technical articles and even humor. Under the new leadership of TLT editor Selim Erhan, TLT is holding steady on course and making even more progress toward a brighter future. Like a favorite uncle, I could not be happier.

Great going, TLT team!

STLE's official magazine

By Maureen Hunter
2007-2009

You won't find TLT at a magazine stand or bookstore. You receive it with your STLE membership, and for 20 years, it has been chosen by the STLE membership as the society's most important benefit. TLT is designed to help each of us to become the best professional in our chosen field. I especially encourage all young professionals, but seasoned experts too, to read it cover to cover. You don't want to miss anything!

TLT is the most cost-effective and time-efficient way to learn about developments in our industry, including trends and challenges, successes and failures and even our colleagues and friends. From the many Feature articles and columns to the Sounding Board survey results and new product writeups, it's incredible how much knowledge one can gain. TLT is not intended to be a peer-reviewed magazine. It has professionally written articles that lead us to scholarly peer-reviewed journals and technical books. It's also interesting to learn about key industry colleagues through Newsmakers and 20 Minutes interview articles and to browse the many advertisements. There is even a section on upcoming industry conferences and events to help plan your own calendar.

TLT also can be used as a prompt for investigating various fascinating topics.

TLT also can be used as a prompt for investigating various fascinating topics. A rich variety of topics that at first glance seem to be outside of our industry will engage and amuse you. With new ideas, knowledge of emerging trends and the comradery found in our industry, young professionals should understand the achievements they too can reach. Reading TLT gives each one of us perspective on the breadth and complexity of our industry and how important we are to the future of our ever-changing world.

20 years of progress

By Evan Zabawski
2009-2021

During my tenure as editor, I saw many changes implemented to improve both the quality and accessibility of TLT. The change of which I am most proud is STLE's self-hosted digital archive of all the digital editions of TLT. I cannot help but feel a little pride when I see a TLT article as one of the top hits in an internet search, but doubly so when the source is STLE's website.

The simplicity and ease of sharing articles also has significantly increased the amount of STLE content I see on social media as well. I am confident that extending the reach of TLT in both manners has only elevated TLT's status outside of STLE's membership.

While other industry publications have either reduced the frequency of issues, moved away from print issues or simply shuttered, TLT has thrived. The first digital issues were typically 60-80 pages, including a Tribology Transaction reprint that took up about 10% of the magazine, and though the reprint is no longer a regular feature, current issues typically range from 80 to more than 100 pages. This is certainly a testament to the hard work by the TLT staff who bring all the content and advertising together.

TLT has thrived.

These are just a few examples of the many ways TLT has progressed in its 20 years, and we will continue to see it evolve to meet the needs of STLE members. I used to look forward to each issue arriving in the mail, but now I have often already previewed some of the articles online by the time it arrives—even I have evolved as a reader!

I wish TLT a happy anniversary and cannot wait to see how it continues to grow!

TLT and the benefits of taking active roles within STLE

By Selim Erhan
2021-present

I was honored when the TLT editor job was offered.

When you read the comments from the previous TLT editors, you notice a great passion to continuously improve the magazine, and STLE in general. This passion is partly due to the person but also partly because of the rich, encouraging and fruitful environment that STLE gives us.

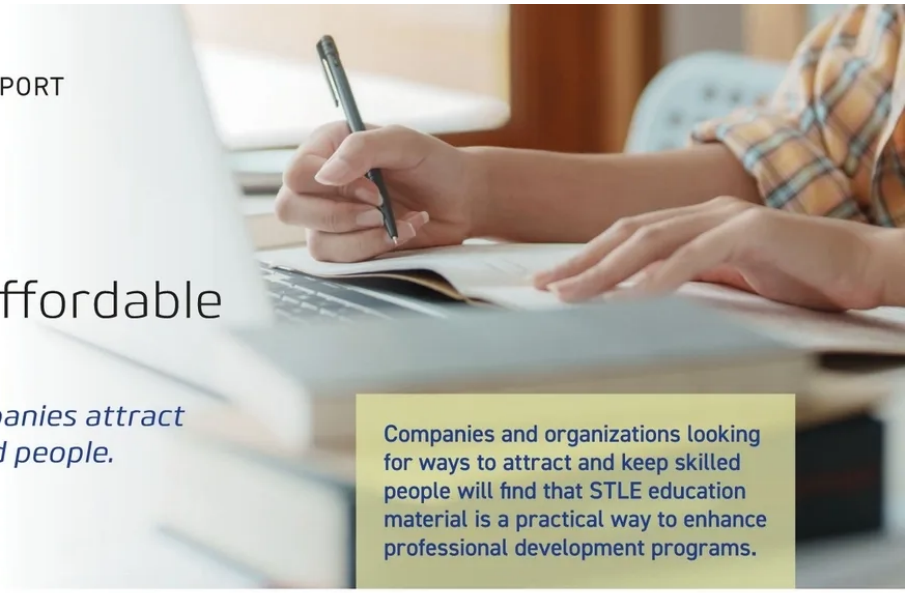
I was involved with STLE since we started doing research on lubricants when I was at the USDA's National Center for Agricultural Utilization Research, and I joined the society in 2000. STLE provided very valuable information, courses in lubrication and metalworking and gave us a very detailed exposure to the lubricant world. Throughout the years STLE kept evolving with new literature, courses and conferences with very informative contents.

I became more involved with the committees when I moved to Chicago and started working as the education co-chair in the STLE Chicago Section. I was very impressed at the level of professionalism, warm support and high quality of the programs that were brought forward by and to the members. As I became more involved with STLE, I was excited to see TLT come alive in 2003. I made sure to read through every issue.

My enthusiasm within STLE must have been contagious because I see many colleagues that I connected with through my various jobs participating and taking active roles and advancing on the same paths with the same enjoyment.

Just as I was entering a saturation level in my career, I was asked by colleagues if I would consider the TLT editor position. I was always impressed with the quality of TLT and looked forward to the monthly issues. I was honored when the TLT editor job was offered. Since accepting the position, my experience in this role has raised me to an even higher level of education and a satisfaction of being able to contribute to a society I have benefitted from so much. It also allowed me to work together with the previous TLT editors, which was very informative, and the professional STLE staff that orchestrates the journals, magazines, books and conferences. It is continuing to be a wonderful experience with truly wonderful people! I strongly encourage my colleagues to get involved in STLE in any way you can!

HEADQUARTERS REPORT



Invest in affordable education

It's how top companies attract and keep talented people.

Companies and organizations looking for ways to attract and keep skilled people will find that STLE education material is a practical way to enhance professional development programs.

By Edward P. Salek, CAE
Executive Director

Workforce issues are prominent among the list of top challenges identified in STLE's most recent member needs study. Convincing younger workers to enter the field was the most pressing concern. Once people are in the industry, respondents also worry about workforce development, training and retention.

What does draw people to an industry or a specific company—especially in a field like tribology and lubricants that may seem less attractive to younger professionals?

The deciding factor, according to a study that questioned 6,600 professionals worldwide, is often professional development. This research, known as the Emeritus Global Workplace Skills Study 2023, found that 74% of respondents would choose to work at an organization that invested in their education over one that didn't.[1]

Emeritus is a company that collaborates with universities to provide several types of online education programs. Its goal is to make high-quality education more accessible and affordable. According to the Emeritus website **(https://emeritus.org)**, its programs have educated 250,000 individuals in 80 countries.

STLE shares the goal of accessible and affordable education, albeit on a smaller scale. Companies and organizations looking for ways to attract and keep skilled people will find that STLE education material is a practical way to enhance professional development programs. Here are five options to consider.

Online short courses are designed for those looking for essential information on technical topics. These self-directed course offerings include basic lubrication, fluid management and recycling, lubrication composition and metalworking fluids. Priced at $79 per course for STLE members and $99 for nonmembers, the courses are intended for individuals new to the industry or needing further understanding on specific content areas.

Courses are hosted on the STLE Learning Management System **(www.pathlms.com/stle)**, which also provides access to a variety of other educational resources. This includes more than 80 recorded webinars organized into nine topical categories: additives, base oils, electric vehicles, grease, lubricant applications, lubrication fundamentals, metalworking fluids, oil analysis/condition monitoring and tribology applications. These are priced at $39 for members and $59 for nonmembers.

STLE also offers two online programs that examine some of the most pressing technical issues or trends in tribology and lubricants. Webinars, facilitated by industry experts, offer practical solutions to problems or issues that participants can apply in their own organization. A recent webinar covered the American Petroleum Institute's (API's) work on a Lubricants Life Cycle Assessment and Carbon Footprinting methodology.

The STLE Industry Insights program is a one-hour live online discussion dealing with current technical topics. For example, a recent session covered regulatory efforts to control or ban the PFAS class of chemicals in Europe and the U.S. The format combines an opening presentation with dialog about the problems, challenges and opportunities related to a given topic. This program is open to STLE members only and is presented on a monthly basis. For more information, visit **www.stle.org/IndustryInsights**.

The fifth item is equally valuable but presented in the form of an industry podcast. Perfecting Motion®: Tribology and the Quest for Sustainability, hosted by Dr. Neil Canter, STLE advisor – technical programs and services, features conversations with leading industry professionals. At the core of each program is the growing recognition that tribology has a critical role to play in efforts to save energy, reduce greenhouse gas emissions, implement sustainability and achieve climate change mitigation goals.

The podcast is free and can be accessed at **www.stle.org/podcast** or through any of the popular streaming services.

To find upcoming STLE live events, visit **www.pathlms.com/stle/events**.

STLE is widely recognized as the foremost provider of non-commercial technical education to the lubrication field. Going forward, the 2023-2026 Strategic Plan calls for expanding continuing professional educational content to assist more professionals at all career stages. Visit **www.stle.org** for the latest information and offers.

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

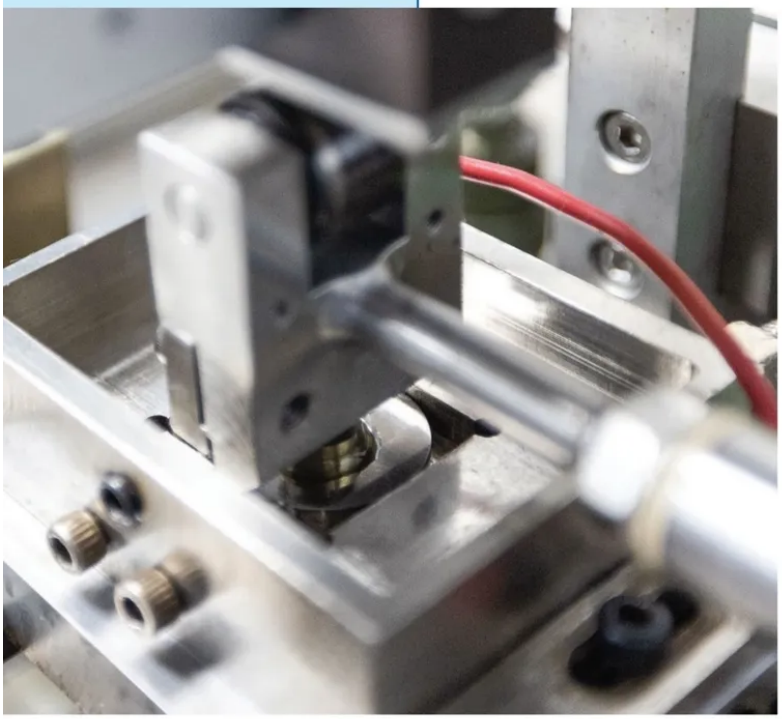
1. **www.emeritus.org/global-workplace-skills-study-2023**

TECH BEAT

Superlubricity in a common bearing system

Disk-on-flat reciprocating sliding tests were conducted with a carbon nanotube-coated stainless steel disk under MQL conditions.

By Dr. Neil Canter
Contributing Editor



HIGHLIGHTS

Superlubricity has now been demonstrated on a CNT-coated stainless steel disk under macroscale steel-steel sliding conditions in an ambient environment.

Coefficient of friction values declined into the superlubricity range after 5-50 cycles of the experiment and remained in that regime throughout initial testing over 5,000 cycles.

The proposed mechanism suggests that the CNT coating is sacrificed *in situ* to form a tribofilm that creates the conditions for superlubricity.

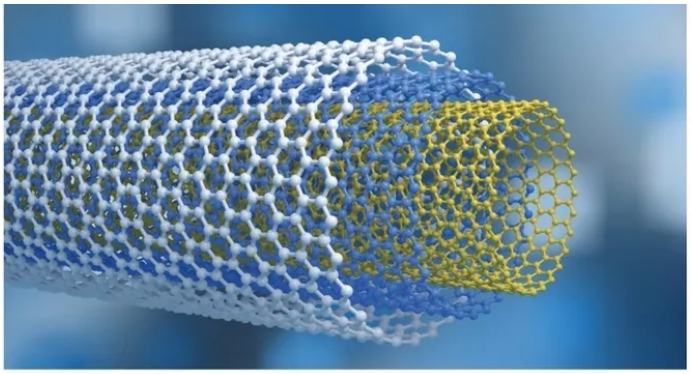
Figure 1. **The tribometer shown was used to conduct disk-on-flat reciprocating sliding tests to achieve superlubricity, or nearly friction-less sliding, under ambient conditions.** *Figure courtesy of Oak Ridge National Laboratory.*

Longer running tests demonstrated that superlubricity proved to be very durable with no change in the coefficient of friction observed for over 12 days.

Improving the efficiency of machinery remains a longstanding goal of tribology researchers. Achieving superlubricity, or nearly frictionless sliding, which occurs when the coefficient of friction is less than 0.01, represents an approach for meeting this goal.

Two past TLT articles discuss work conducted on superlubricity. In 2015,[1] researchers first saw superlubricity at the macroscale experimentally. The experiment involved a graphene-coated surface sliding against a diamond-like carbon (DLC)-coated surface under dry conditions. This interaction triggered the formation of graphene nanoscrolls that were stabilized through introduction of nanodiamond particles.

Using a ball-on-disk tribometer operating under a nitrogen atmosphere, superlubricity was observed when a ball coated with hydrogenated DLC was slid against a surface containing two-dimensional molybdenum disulfide and nanodiamonds.[2] Coefficient of friction values in the 0.005 range were achieved due to a stress-induced



chemical reaction that converted nanodiamonds into onion-like carbon structures.

STLE Fellow Dr. Jun Qu, group leader of surface engineering and tribology, distinguished R&D staff at Oak Ridge National Laboratory in Oak Ridge, Tenn., says, "Superlubricity is often only observed under very limited conditions that require ultrahigh vacuum or inert environments. In more recent cases, under ambient environments, water-based lubricants were used on very smooth ceramic surfaces to produce superlubricity under high-speed sliding conditions."

While there is direct evidence of superlubricity, Qu believes that determining an approach that can be used with existing hydrocarbon lubricants will facilitate new opportunities for improving current machinery. He says, "In common applications, such as bearings, the solid surfaces often are steels, and lubricants are based on mineral oil or some other type of hydrocarbon."

One option is to use carbon nanotubes (CNTs) under hydrocarbon lubrication to produce superlubricity. CNTs are cylindrical tubes made of sp^2 hybridized carbon atoms bonded into a network of hexagonal lattice structures similar to graphene. Depending upon the number of graphene sheets inside, CNTs may be identified as single, double or multi-wall.

One of Qu's colleagues, STLE member Dr. Chanaka Kumara, developed a procedure for synthesizing CNTs through a chemical vapor deposition (CVD) process on stainless steels and tool steels. Kumara says, "Initially, the steel surface is oxidized at elevated temperature to produce metal oxide nanoparticles on its surface. Then introduction of a carbon source, ethanol, under a reduced atmosphere at elevated temperature, led to the formation of a black color, CNT-coated, steel surface." Both tool steel and stainless steel alloys are commonly used in bearings.

Qu and Kumara have now demonstrated superlubricity on a CNT-coated stainless steel disk under macroscale steel-steel sliding conditions in an ambient environment.

Sacrificial coating

The researchers conducted disk-on-flat reciprocating sliding tests *(see Figure 1)* with a CNT-coated Type 316 stainless steel disk, and an uncoated M2 tool steel flat at 0.5 Hz oscillation with a stroke of 10 millimeters. One drop of 4 cSt polyalphaolefin (PAO) was applied to the interface, basically a minimum quantity lubrication (MQL) condition.

Qu says, "For the first 5-150 cycles of the experiment, coefficient of friction values remained in the 0.05-0.1 range, which is typical of a boundary lubrication regime. Further cycling led to a rapid reduction in the coefficient of friction into the superlubricity range (0.0001-0.007). Of significance is superlubricity was maintained throughout initial testing over 5,000 cycles, which represents 100 meters of sliding that took 2.8 hours to complete."

Longer running tests demonstrated that durability of superlubricity. Qu says, "The reciprocating sliding tests were run for over 12 days (525,000 cycles) with no increase in the coefficient of friction. Additional droplets of PAO were added every three days to compensate for evaporation. At the time of addition, the test was stopped and then resumed. A friction spike was then observed, but then the coefficient of friction declined to below 0.01."

While it is tempting to hypothesize that the mechanism for generating superlubricity might involve CNT segments as mini-rollers at the contact interface, there is no direct evidence for this phenomenon. On the other hand, the multi-wall CNTs are composed of rolled-up sheets of graphene. Qu says, "During the run-in phase of the tribotest, the CNTs fracture into small graphene flakes. Continuing thermomechanical stresses facilitate oxidation and mixing of the graphene flakes with metallic wear debris from the steel surfaces to deposit a graphene-rich tribofilm on both the contact surfaces, leading to an easy-to-shear interface."

This mechanism suggests that the CNT coating is sacrificed *in situ* to form a tribofilm that creates the conditions in the reciprocating sliding tests for superlubricity. Scanning transmission electron microscopy and elemental mapping conducted using energy-dispersive X-ray spectroscopy data support this hypothesis by finding a mixture of carbon and metallic nanoparticles (primarily iron and chromium) in the tribofilm.

PAO, although merely one droplet, performs an important role to ensure that superlubricity is realized. Qu explains, "The oil prevents scuffing failure during the running-in phase, reduces adhesion between the two contact surfaces, minimizes the wear rate, removes wear debris from the interface and helps to align the graphene flakes in the tribofilm to being presumably parallel to the metal surface. In experiments run dry without oil, we noticed immediate scuffing and the coefficient of friction values were two orders of magnitude above the superlubricity level."

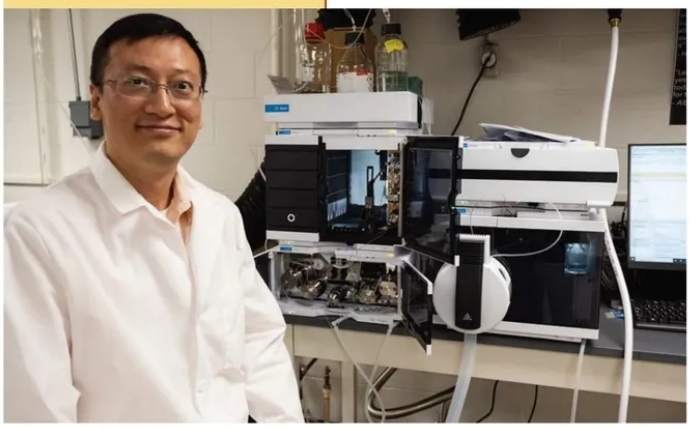
The researchers intend to get a better understanding of the mechanism. Qu says, "We have seen that raising the temperature above 50 C leads to an increase in the coefficient of friction above superlubricity. Understanding this phenomenon will hopefully broaden the practical applications."

Qu's team also intends to evaluate other lubricants besides PAO to determine their effects. Candidates include mineral oils, polyalkylene glycols (PAGs) and esters. Additional information can be found in a recent reference[3] or by contacting Qu at ***qujn@ornbl.gov***.

1. Canter, N. (2015), "Superlubricity: Seen at the macroscale for the first time," TLT, **71** (10), pp. 10-11. Available at **www.stle.org/files/TLTArchives/2015/10_October/Tech_Beat_I.aspx**.
2. Canter, N. (2018), "Generation of long-lasting superlubricity at the macroscale," TLT, **74** (8), pp. 12-13. Available at **www.stle.org/files/TLTArchives/2018/08_August/Tech_Beat_I.aspx**.
3. Kumara, C., Lance, M. and Qu, J. (2023), "Macroscale superlubricity by a sacrificial carbon nanotube coating," *Materials Today Nano*, **21**, 100297.

New approach for removing PFAS from spent filter media

Greater than 90% of PFAS present in spent filter media can be removed in less than 40 seconds of high-frequency induction heating.



HIGHLIGHTS

Concern has increased about the potential harmful effects of perfluoro- and polyfluoroalkyl substances (known as PFAS) to animals and human beings.

PFAS removal from water has proven effective using granular activated carbon and anion exchange resins, but challenges persist with removing solid PFAS from exhausted carbon and resins.

A new technique known as high-frequency induction heating displays promise in removing PFAS from spent media in only a few minutes at elevated temperatures.

Figure 2. **Associate professor Feng Xiao led a research team that has developed a new technique known as high-frequency induction heating that can efficiently remove PFAS from spent media.** *Figure courtesy of the University of Missouri.*

Perfluoro- and polyfluoroalkyl substances (known as PFAS) have become of significant concern for users and manufacturers of lubricants in the recent past. The concern is due to PFAS causing health effects in animal studies and potentially being considered to be harmful to human beings.

The concern about potential PFAS health risks originates from the difficulty in decomposing them. This class of chemical substances are known as "forever chemicals." In lubricants, PFAS are used to manufacture fluorinated lubricants, and are precursors to fluoroelastomers used in seals. Their presence in a wide range of applications means they are found throughout the environment, specifically in ground water used for consumer and industrial use.

Regulatory agencies have initiated programs to limit the use of PFAS as a means to reduce their presence in the environment. In the European Union (EU), The European Chemicals Agency (ECHA) is now considering a proposal from authorities in member countries to ban approximately 10,000 PFAS substances from use in the EU.[1] The U.S. EPA is proposing maximum contaminant levels for six PFAS substances in drinking water.[2] For two of the substances, perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), EPA is proposing maximum contaminant levels of 4.0 parts per trillion.

> The concern about potential PFAS health risks originates from the difficulty in decomposing them.

Feng Xiao, associate professor in the department of civil and environmental engineering at the University of Missouri in Columbia, Miss., says, "PFAS removal from water can be accomplished using granular activated carbon (GAC) and anion exchange (AIX) resins. While effective, challenges persist with removing solid PFAS from exhausted carbon and resins."

Using inorganic salts (such as sodium chloride) or methanol has been tried but is ineffective because PFAS is far more hydrophobic than inorganic anions such as chloride. Thermal methods such as smoldering and thermal desorption have shown promise but require a high amount of energy and are time consuming. Incineration of PFAS-spent media is another option that is very expensive and can generate toxic chlorinated/brominated dioxins and furans.

With the concern rising about PFAS contaminating lubricant manufacturing and end-user facilities through a number of ways including water, a new approach is needed to effectively remove it from spent media. High-frequency induction heating has now been determined to be a technique for removing PFAS from spent media in a fast and effective manner.

The Joule effect

Xiao and his research group determined that a technique known as high-frequency

One noteworthy application where PFAS contamination is of concern is in ground water used for consumer and industrial use.

induction heating can be used to effectively remove PFAS from spent media in only a few minutes at elevated temperatures *(see Figure 2)*. He says, "Induction heating utilizes the Joule effect, which involves the production of heat in a metallic reactor by electromagnetic induction without the need for direct contact between the heater and the reactor."

An inductive reactor was used in conducting experiments with all six PFAS in the EPA regulation (including PFOA and PFOS) and five derivatives.

Xiao says, "Heating PFAS samples by high-frequency induction heating for less than 40 seconds resulted in the degradation of greater than 90% of the PFAS. If the induction time was extended to greater than 40 seconds, more than 99.5% of the PFAS was decomposed. Each of the PFAS substances had different rates of decomposition, which meant that extending the induction heating time to two to three minutes was needed to completely degrade the potassium salt of PFOS."

As part of this study, Xiao and his students also decided to better understand how PFAS undergo phase transitions (melting and evaporation). Based on thermogravimetric analysis and differential scanning spectroscopy, the researchers found preliminary evidence that the rate-determining step in the decomposition of PFAS are phase transitions.

A final advantage of the induction method is safety because the use of an open flame is not required, and combustion does not occur. Xiao says, "One concern is that we noticed corrosion in the reactor probably due to the interaction of reactive fluorine species (such as fluorine radicals and hydrogen fluoride) with the reactor to produce metal fluoride. We previously determined that adding amendments to PFAS prior to heating minimizes the formation of fluorine derivatives reducing the possibility of corrosion."

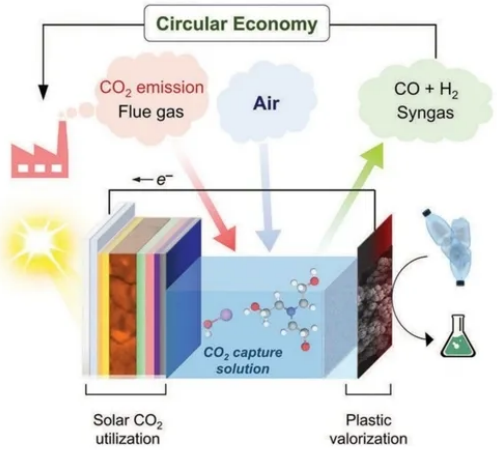
Future work will entail gaining a better understanding of the decomposition mechanism for PFAS. Xiao adds, "We also will be using this inductive heating approach to develop practical solutions for applications where PFAS is present and must be removed."

Additional information can be found in a recent article[3] or by contacting Xiao at ***feng.xiao@missouri.edu***.

1. **https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal**
2. **www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas**
3. Xiao, F., Sasi, P., Alinezhad, A., Sun, R. and Ali, M. (2023), "Thermal phase transition and rapid degradation of forever chemicals (PFAS) in spent media using induction heating," *ACS ES&T Engineering*, **https://doi.org/10.1021/acsestengg.3c00114**.

Production of synthesis gas from carbon dioxide using solar energy

This newly developed process has the potential to offer a sustainable pathway for producing gas-to-liquid base stocks using the Fischer Tropsch process.



HIGHLIGHTS

A photoelectrocatalytic reduction process was developed that not only converts carbon dioxide to syngas but also oxidizes waste plastic-derived ethylene glycol to glycolic acid.

Initial work involved evaluation of concentrated carbon dioxide, flue gas and air.

The balance required between the capture and utilization steps depends upon the concentration of carbon dioxide available.

Figure 3. **This photoelectrocatalytic reduction process is the only solar drive process for utilizing captured carbon dioxide.** *Figure courtesy of the University of Cambridge.*

Research is ongoing to identify cost effective pathways for converting the greenhouse gas carbon dioxide into useful derivatives that can be used as building blocks to manufacture lubricant base stocks and additives. One process that is actively under evaluation is the photoelectrocatalytic carbon dioxide reduction reaction.

In a previous TLT article,[1] a new type of catalyst was reported that combines copper with nickel to convert carbon dioxide to carbon monoxide and then to the hydrocarbon, ethylene. The copper, nickel hybrid catalyst was used at an optimum ratio of 10:1 under alkaline pH conditions. A Faradaic efficiency of 66% was achieved with this hybrid catalyst. Better selectivity for ethylene was obtained as the reaction conditions minimized the transformation of water to hydrogen.

Utilizing carbon dioxide captured by current approaches has proven to be expensive and to require a large amount of energy. Dr. Sayan Kar, postdoctoral scientist in the Yusuf Hamied department of chemistry at the University of Cambridge in Cambridge, UK, says, "The current approach is to capture carbon dioxide in alkanolamine solutions, and then use desorption and compression steps to produce a pure carbon dioxide stream that involves heating up solutions at temperatures up to 100 C. Carbon dioxide desorbs at this high temperature, which is then used for various purposes, but this is an energy intensive process. The challenge is to overcome the thermodynamic stability of captured carbon dioxide without requiring significant energy."

A more efficient approach is to directly capture carbon dioxide and then convert it into a derivative through a sustainable method such as the use of solar energy. Kar says, "We have been working to utilize sunlight to capture and convert carbon dioxide over the past five or six years using a series of heterogeneous catalysts.

Kar, his colleagues Dr. Motiar Rahaman, senior postdoctoral scientist and Marie-Curie Fellow, and Dr. Erwin Reisner, professor of energy and sustainability, have now developed a process using solar energy to efficiently convert captured carbon dioxide into syngas, which is a combination of carbon monoxide and hydrogen. Of interest to the lubricant industry is that this process has the potential to offer a sustainable

pathway for producing gas-to-liquid base stocks using the Fischer Tropsch process.

Solar-driven photoelectrochemical (PEC) process

The researchers developed an approach that combines carbon dioxide capture and reduction to syngas with oxidation of waste plastic-derived ethylene glycol to glycolic acid. The latter intermediate has applications in the pharmaceutical, food and textile industries. The solar-driven photoelectrochemical (PEC) process is shown in Figure 3. A two-compartment, three-electrode setup was used.

Kar says, "We used a cobalt (II) phthalocyanine molecular catalyst in the carbon dioxide reduction process because this substance works well in producing syngas at lower overpotentials. Carbon dioxide capture was achieved through the use of aqueous solutions of amines such as monoethanolamine (MEA) and triethanolamine (TEA) as well as sodium hydroxide." The catalyst was immobilized on multi-walled carbon nanotubes, then drop-cast on a graphite foil substrate, and finally attached to a perovskite solar cell to produce the photocathode.

A more efficient approach is to directly capture carbon dioxide and then convert it into a derivative through a sustainable method such as the use of solar energy.

The initial challenge facing the researchers was to identify a complementary oxidation process to work with the carbon dioxide reduction reaction. Oxidation of water was attempted, but the researchers determined that low carbon monoxide production was obtained, due to the difficulty of the water oxidation process.

Kar says, "To overcome the issue of water oxidation, we switched to a strategy using ethylene glycol oxidation obtained from discarded polyethylene terephthalate plastic waste. This allowed us to increase our production of synthesis gas by carbon dioxide reduction, and at the same time to upcycle plastic waste to useful chemical derivatives that would otherwise go to a landfill. A copper palladium alloy electrodeposited on a nickel foam was used as the anode to catalyze the oxidation of ethylene glycol to glycolic acid under alkaline conditions."

A concentrated carbon dioxide (99.995%) gas stream was used in the first series of tests. The faradaic efficiency for syngas formation was found to be greater than 95%, and the carbon monoxide to hydrogen ratio in this product was 1:2.

Kar says, "TEA was selected as the amine for use with the high purity carbon dioxide stream because the MEA adduct of carbon dioxide is too thermodynamically stable. The result is that carbon dioxide is not as readily available to be converted to carbon monoxide in the reduction step. As a weaker base, the TEA adduct of carbon dioxide is not as stable."

The successful demonstration of the PEC process led the researchers to determine additional steps toward commercialization by evaluating two common gas streams that contain carbon dioxide: flue gas and air. Flue gas is a post-combustion process produced from large industrial plants and also from automotive exhaust. A simulated flue gas stream containing 15% carbon dioxide, 4% oxygen and 81% nitrogen was used. Air with an ultra-dilute concentration of carbon dioxide (approximately 420 ppm) also was evaluated.

In both cases, the conversion to carbon monoxide and syngas was lower. Kar says, "The ratio of carbon dioxide to hydrogen in the flue gas experiments was 1:4 and in the evaluation of air was 1:30. We also found that carbon dioxide capture from air was best handled using the more alkaline bases, sodium hydroxide, as compared to TEA." The need to adjust the PEC depending upon the concentration of carbon dioxide available highlights the balance required between the capture and utilization steps.

Rahaman says, "Our ability to demonstrate this approach, the only solar-driven process for utilizing captured carbon dioxide, leads us to optimize the system to increase conversion to syngas. The solar cell also has proven to be able to operate successfully for days. We are working to extend the durability from days to years. Ultimately, an approach needs to be found to move this process from the lab scale to the commercial scale."

Kar mentioned that future work also will involve developing pathways to use the PEC process to manufacture methanol and ethanol from carbon dioxide. Additional information can be found in a recent article[2] or by contacting Reisner at ***resiner@ch.cam.ac.uk***.

1. Canter, N. (2023), "Conversion of carbon dioxide to ethylene," TLT, **79** (5), pp. 20-21. Available at **www.stle.org/files/TLTArchives/2023/05_May/Tech_Beat_II.aspx**.
2. Kar, S., Rahaman, M., Andrei, V., Bhattacharjee, S., Roy, S. and Reisner, E. (2023), "Integrated capture and solar-driven utilization of CO_2 from flue gas and air," *Joule*, **7** (7), pp. 1496-1514.

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***.

Industry leaders send their best wishes

TLT's readers and advertisers are the two most important supporters of the magazine. We gave our readers a chance to share their thoughts about TLT in this month's TLT Insights, and we also asked advertisers to comment on the 20-year anniversary. Their congratulatory messages are below. TLT would like to thank both our readers and our advertisers for their ongoing support.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Congratulations to TLT for 20 years of being a trusted resource and providing relevant, informative and innovation-provoking content to the lubricants industry!
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Ergon's HyGold team congratulates TLT for two outstanding decades of publishing excellence and for your contributions to the lubricants industry.
ERGON
HyGold
Base Oils
Celebrating two decades of dedicated industry service— a resounding applause to TLT and their commitment to us all!
FOCUS CHEMICAL
Thank you to TLT for serving as a cornerstone of open innovation within the tribology community for 20 years.
FUNCTIONAL PRODUCTS INC.
Innovative Chemistry for Lubricants
Together we can make a lasting impact in the lubricant industry and continue to drive outstanding results. Happy birthday, TLT!
Infineum


Thank you TLT for 20 solid years of technical excellence, impact and service to the lubricants industry. Congratulations on this milestone!
Congratulations TLT staff and writers for 20 years of high-quality valuable content. Looking forward to the next 20 years!
SwRI
SOUTHWEST RESEARCH INSTITUTE
TLT is the go-to resource for technical articles and info about our tribology community. Congrats on 20 years!
TIMKEN
Congratulations, TLT, on 20 great years of excellent content and teaching. Here's to another 20!
Doug Sackett
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Board of Directors, STLE
United Color Manufacturing, the world's leader in petroleum dyes, markers and fluorescent tracers, congratulates TLT on 20 years of reporting excellence.
UCM
LEADERS IN COLOR CHEMISTRY
Univar Solutions would like to congratulate TLT on achieving this 20-year milestone, filled with outstanding contributions to the lubricants industry.
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Hundreds of companies in the lubricants industry have chosen TLT to communicate their marketing messages to more than 15,000 individuals each month. STLE and TLT are grateful for the many advertisers that have contributed these past 20 years.

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TLT INSIGHTS

Thoughts on TLT

Executive Summary
Every month in Sounding Board, TLT asks readers to share their thoughts, ideas and feelings on the key issues impacting the tribology and lubrication industry. This month we also asked readers to comment on TLT itself. Thank you for your loyalty to TLT—we appreciate your support!

Q.1 What do you think of TLT?

It is a good and informative publication.

Informative, but I seem to pick the articles of interest and skip others. I should spend more time reviewing all articles.

I have been reading it for 20 years and have been using the information for knowledge in the lubrication field.

TLT is the most interesting and varied magazine for our industry. I only wish it was weekly!

It's important for my job and good for studying/getting information.

A great resource to keep up to date on current and emerging technologies.

I enjoy it—I think it is really well done and informative. It's pertinent information to our industry.

It's a great publication that has evolved in a good way over the years. It always manages to stay on top of current issues and offer professional insights that those in the industry won't find anywhere else.

TLT is among the best magazines for updates in the lubrication and tribology world.

TLT articles are very informative and relevant.

The very best lubrication magazine that I've read.

Generally good, authoritative and viewpoints supported.

10/10 best lubricant magazine.

Congratulations to TLT for reaching its 20-year anniversary. Thanks to the editors, editorial staff and readers for keeping it an excellent resource for industrial and academic news, cutting edge technologies and society and community activities. I hope TLT will keep going strong and have a great, successful future!

Great source for industrial trends and technical updates.

It is a quality magazine and provides knowledge in varieties of tribology and engineering topics.

Excellent space to acquire knowledge.

Very educational.

I receive a lot of magazines about lubricants in general, but TLT is the one I prefer to keep close. There is a lot of information that I can use daily and that I share with other field engineers.

I really enjoy TLT and learn from the technical side. I do wish there were more practical applications.

It is a good magazine, published by a knowledgeable publisher/editor-in-chief. You get the technical expertise and innovative solutions for your formulating needs.

Some articles are relevant and interesting.

Very good articles covering a wide range of topics.

Wonderful source of information—it has everything topical and relevant in today's times. Great job by the publisher and her team.

I think it is great. I have enjoyed lots of the articles. I don't always take the time to read everything.

TLT has been an important piece of STLE's recognition. A wide variety of articles has appeared over TLT's two decades, and I'm personally gratified to have been a part of the TLT legacy, having written a bimonthly segment for nearly 10 years.

TLT is superlative. I look forward to receiving TLT in the mail.

An outstanding resource of tribology, lubrication and reliability sources. Very well rounded in its content to provide informative articles.

Very technical and sometimes research-oriented for selected topics, which is good but maybe adding more business-oriented topics would be beneficial (e.g., trends, market intelligence).

A great resource to stay up to date with the latest in tribology.

It's a great magazine.

It's a great resource for information for lubrication professionals.

Great trade journal, excellent resource for news and technical information.

I think it is an excellent publication that allows us to keep up to date with the latest trends in the world of lubrication.

Great publication. I learn something from each issue. I like that it covers many topics.

Good resource to stay informed.

It is a good magazine. It has a mixture of things about tribology and the people involved.

The very best lubrication magazine that I've read.

TLT is a professional and diverse publication.

I like that it covers a wide range of topics.

Good organization—bringing different companies under one umbrella where we can share of our expertise and knowledge. I like to read TLT for the information sharing and future development.

Good magazine with interesting articles from key industry people.

Excellent—perfect mixture of topics and depth. I value the magazine most of all the industry trade magazines available.

Nice overview of recent news and developments.

TLT provides a good variety of topics and current technology articles. Being new to the workforce, I especially appreciate the archives to look over previous years.

It's a great resource for lubrication technological industries, especially metalworking fluids, oil and gas industry and internal combustion engine and electric vehicle emerging trends.

Excellent publications (hard copy and online) with good information and details.

Broadest combo of news and technology for the tribology/lubrication engineering industry.

2007 2008 2009 2010 2011 2012

How much time do you spend reading TLT each month?	
Less than 15 minutes	6%
15-30 minutes	25%
30-45 minutes	41%
45-60 minutes	19%
More than 60 minutes	9%

Based on an informal poll sent to 15,000 TLT readers.

The most informative source of information on lubricants to be found in one place.

Very professional magazine, informative and helpful.

I think TLT is informative and easy to read (as it explains more of the basics with words, instead of deep detail with formulas). Images are very well chosen to support the text. Although it touches mostly on the basics, I often find something new (or to refresh my knowledge).

Great tool for industry information.

Q.2 Which topics are you most excited to read about in TLT?

What the future holds for lubricants.

More on the heavy truck fleet—at this time that is my focus.

Peoples' interviews, practical information.

I do not have any particular topic—I enjoy the diversity and reading about all things tribology focused.

Lubrication, lubrication systems, new technology.

Past experiences and case studies from lubrication experts, new lubrication standards.

Anything that is new to me. Sometimes it's an article regarding the industry's future or a new spin on product technology.

Anything new and leading edge!

Lubricants, electric vehicle fluids, oil analysis, friction and wear, etc.

Digital tribology.

Transportation lubrication.

New technology, raw materials and finished products.

Tribotesting, surface engineering, solid lubrication, 20 Minutes interviews, Feature articles and Sounding Board.

Gear oils and hydraulic fluids.

Biolubricants.

Lubrication Fundamentals, Webinars and Feature articles.

Industrial trends, new tribology and new materials.

Fuels and lubricants especially, maybe new R&D.

Electric vehicles and tribochemistry.

The most interesting topics for me are new areas and innovations, plant maintenance, new products and networking.

Just about any topic that is practical and applies to in-use situations, not the theoretical or pre-design phase ones.

2013 2014 2015 2016 2017 2018

Topics related to the lubrication of bearings and gears.

Supply chain disruptions will continue to drive lubricant prices and availability. Most economists say the old way of doing business is no more.

What the future holds for lubricants.

I like Lubrication Fundamentals because sometimes the author will explain a subject by using a metaphor that makes it so much easier than what I use, depending on the subject. Market Trends is the first thing I read and sometimes the only thing.

Both practical technical applications and developments of new lubricant additives.

Metalworking fluids and lubricating greases.

Rolling bearings and gears, surface texture and stress.

Lubes and additives.

Anything involving electric vehicles.

Interviews with those with extensive experience in the field. Also research articles.

Main Feature articles especially about new emerging areas such as electric vehicles, green solutions, etc. Also 20 Minutes interviews, Sounding Board and President's Report.

The discontinued Evan Zabawski columns about lubrication puzzles. Newsmakers, top stories, promotions and transitions and STLE Local Section scholarships.

The latest trends in the industry and to keep up with the lubrication advancements in our modern-day equipment.

Lubrication and reliability.

Feature articles are the ones that I look at systematically every month.

Lubrication Fundamentals: elastohydrodynamic lubrication, surface roughnesses and electric vehicle tribology.

Automotive gear oils for light-duty and heavy-duty applications.

New developments in the automotive industry.

Oil analysis.

New innovations, market trends and people on the move.

Emulsion science.

Grease, electric vehicles and trends.

Articles on new product development and new technologies.

Development of lubrication and how applications are changing the way we do things. Also, I like coverage of the basics. Some of the most fun reading is the non-lubrication topics.

Those related to metalworking lubricants.

1.) For many years I was excited to read about metalworking fluids. 2.) Recently the exciting articles are about the trends of electric vehicle lubricants and electric vehicle batteries.

Design requirements and challenges for single electric vehicle fluids.

Tribology in electric vehicles.

Lubrication basics and information of Group IV and V lubricants.

Lubricant additive trends.

Sustainable innovations within the industry.

Tribology and interviews.

New lubrications.

Anything that has a surprising scientific finding is exciting to read about. I always learn a handful of things from each issue.

New additive technology articles, regulatory topics of interest to the metalworking fluids industry and news about colleagues in the industry.

Innovative ideas and projects related to chemistry and hardware.

Lubricant formulation challenges, trends and new technologies.

I am a traditional lubrication engineer but am most excited by the concept of biotribology, a field that seems to have located a home.

Natural and synthetic applicants.

Lubricants and additives.

Lubrication Fundamentals, Feature articles, 20 Minutes interviews, etc. As you can see, I read most parts of TLT.

Hydraulics and any activity happening in the lubrication industry.

Editor's Note: *This TLT Insights is based on an informal poll sent to 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 STLT Insights, nor does inclusion of a comment represent an endorsement of the technology by STLE.*

2019 2020 2021 2022 2023

STLE United Kingdom Student Chapter

STLE's newest student chapter discusses why they started the chapter and what they plan on doing in the future.

By Rachel Fowler
Publisher/Editor-in-Chief

STLE United Kingdom Student Chapter
The Quick File:

STLE United Kingdom Student Chapter. From left to right: Nicole Rosik, Roshan Lal and Laure Kyriazis.

stle
UK Student Chapter

The aim of the STLE United Kingdom (UK) Student Chapter is to connect students and those in an early-stage career in tribology with established industrial bodies, to increase the awareness of ongoing research and to promote careers in the field. It was started by STLE members Roshan Lal, Laure Kyriazis and Nicole Rosik, who are all doctor of engineering students at the University of Birmingham, with the Centre for Doctoral Training in Formulation Engineering. As opposed to most existing local chapters, the STLE UK Student Chapter targets all research groups and industries working in tribology and lubrication in the whole UK and is not limited to the University of Birmingham where it was created. This chapter hopes it will lead the way for other local chapters to be created in Europe.

TLT interviewed the STLE UK Student Chapter to discover what other local groups can learn from its innovative programs and approaches. For more information, visit **https://stleukstudents.org**.

TLT: What made you decide to start the STLE UK Student Chapter?

UK Student Chapter: Roshan, together with another colleague from the University of Birmingham, attended the 2022 STLE Annual Meeting in Orlando, Fla. They felt that the UK-based tribologists were lacking the strong network provided by STLE in the U.S., and the individual research groups mostly kept to themselves. At the World Tribology Congress (WTC 2022) in Lyon, France, Roshan and Laure were prompted to start a student chapter in the UK by STLE Fellow Raj Shah, who sits on the STLE Board of Directors.

TLT: What motivates you to volunteer your time and energy to STLE?

UK Student Chapter: We started the STLE UK Student Chapter initially to provide more opportunities to young tribologists than we had when we started our doctoral degrees. As it turns out, we ourselves benefit a lot from this enterprise since it not only provides us with a good opportunity to develop extracurricular skills (e.g., project and people management, communication, teamwork) but also greatly expands our own professional network within the tribology field. Additionally, organizing successful events is quite rewarding, and we have a lot of fun attending them and engaging with the other attendees.

TLT: How do we encourage other young people to pursue careers in tribology?

UK Student Chapter: Tribology is a key sector in the transition to a more sustainable future. Young people are quite concerned about their uncertain future and are willing to make a change for a better world.

Tribology being an interdisciplinary subject, there is always something more to be learned, and we can benefit greatly from each other's perspective and expertise on different aspects of the same application.

TLT: What lessons have you learned that may be useful for other local sections and chapters?

UK Student Chapter: Do not hesitate to seek STLE's support—they are always willing to help. For instance, finding sponsorships is very difficult, especially when you start a new organization from scratch. We utilized the STLE membership directory as a starting point to contact companies in the UK and expanded to include the network we developed attending tribology-focused events. It can take a long time, but it is worth it in the end. Many thanks to our conference sponsors for their invaluable trust.

One common mistake we were doing at first was not allowing enough time ahead of events to plan and advertise them. It resulted in a lot of stress and rushing before the events. We now are a bit more realistic in the deadlines and are a bit more prepared and organized.

STLE United Kingdom Student Chapter Leadership Team

Chair: Roshan Lal, University of Birmingham
Vice chair: Laure Kyriazis, University of Birmingham
Treasurer: Nicole Rosik, University of Birmingham

Recruiting more people on the committee is very time consuming but ends up being rewarding in the long run. We started off just the three of us, but it rapidly became a lot of work for such a small team. We recommend having a clear idea of the different positions and responsibilities available, to divide the workload more easily.

Lastly, don't underestimate the importance of working on your communication. We use our custom-made logo and branding for all platforms (emails, social media posts, business cards, leaflets, posters and the website).

TLT: What are your plans for the future?

UK Student Chapter: After two successful themed seminars, we are organizing TriboLink 2023, the first edition of our annual Conference & Careers Fair, Nov. 6-7, at the Exchange (Birmingham, UK). The aim is to provide young tribologists with the opportunity to present their research and enhance their network by connecting with other researchers and experts in both academia and industry, in a two-day event.

TriboLink 2023 is our first fully in-person event and will feature technical talks, careers workshops, opportunities to network with our sponsoring companies, drinks reception and conference dinner. You can find all information about TriboLink 2023 at the dedicated page on our website *(scan the QR code)*, with the links for abstract submission and registration. Make sure to register—we are looking forward to seeing you at TriboLink 2023!

Acknowledgements:
Many thanks to our conference sponsors: Formulation Engineering CDT, PCS Instruments, Afton Chemical, TriboTonic, Cargill, The Lubrizol Corp. and the Royal Society of Chemistry, and our media partner: Surface Ventures. We also acknowledge our future sponsors who were not fully confirmed at the time of this article being published.

We also would like to thank the School of Engineering (University of Birmingham), the Tribology Group (Imperial College London) and the University of Sheffield for hosting our hybrid events throughout the year.

*You can reach Roshan Lal, Laure Kyriazis, Nicole Rosik and their team at **uk_students@stle.org**, and visit their website at **https://stleukstudents.org** to find out more.*

Bearings

The best lubrication regime depends on the type of bearing and the application in which it is used.

By Dan Holdmeyer
Contributing Editor

One of the simplest types of bearing is the plain bearing, or *journal bearing*, where a shaft is supported by bearing material shaped concentrically with the shaft. The length of the shaft that is within the bearing width is called the journal, and, thus, the name journal bearing *(see Figure 1)*. The bearing metallurgy ideally is softer than the shaft metal. This design dictates that the bearing wears out before the shaft, which is ideal in that it is far less expensive and difficult to replace the bearing compared to replacing the shaft. Proper lubrication, however, will extend the bearing life, possibly to the life of the equipment.

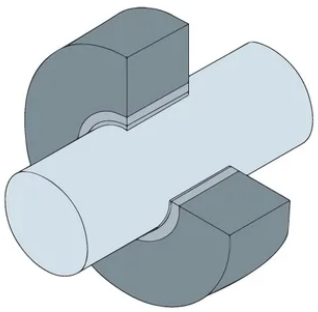
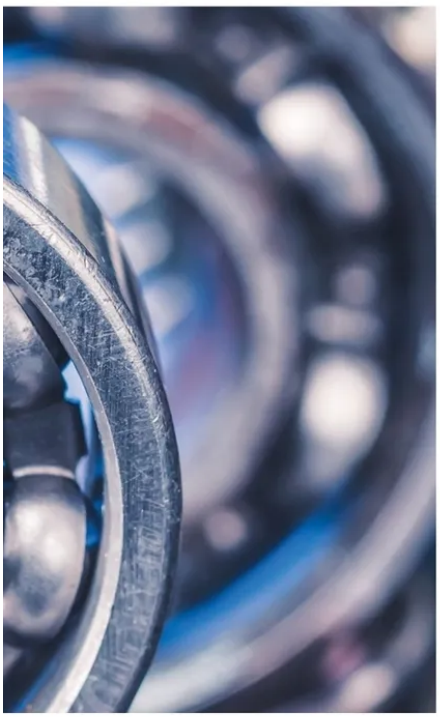


Figure 1. **Plain, or journal, bearing.**

Linear bearings, another form of journal bearings, are often overlooked as bearings. They may also be called slides, guides or ways.

Rolling element bearings are comprised of an inner race, an outer race and elements that roll between the two races (much more complicated than a plain bearing). The rolling elements are held in place by a cage to keep them evenly spaced between the inner and outer races *(see Figure 2)*. These rolling elements reduce bearing friction with minimal lubrication and are sometimes referred to as anti-friction bearings, but that does not mean no friction; thus, we still need to lubricate and protect these bearings.

Rolling element bearings are classified by the shape of the rolling elements incorporated. Figure 3 on page 40 shows just a few bearing types. Some bearings have two rows of rolling elements between the races and are simply called "double row ball," or "double barrel roller," bearings,



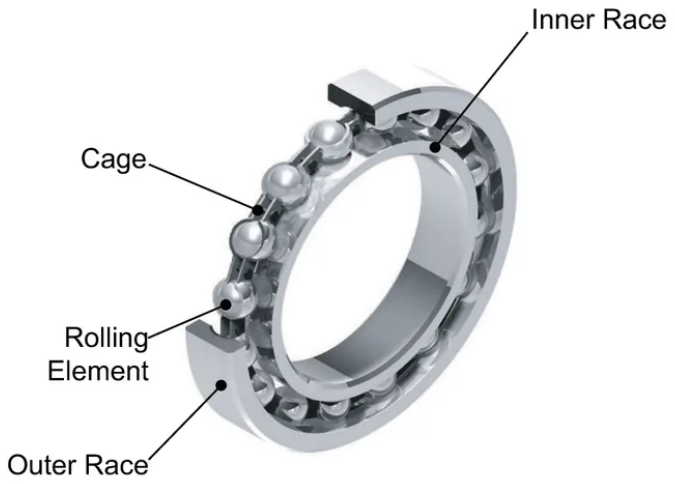


Figure 2. **Rolling element bearing components.**

for example. Double row bearings are used to support heavier radial loads relative to their single row counterparts. Additionally, roller bearings in general have greater load carrying capacity than ball bearings.

Most often the outer race is held stationary with the inner race attached to a rotating shaft. Common applications are in turbines and gearboxes where the bearings support the rotating shafts. The steer axle bearings of rear-wheel-drive cars are an example of the inner race remaining stationary and the outer race rotating. These bearings not only carry a radial load from the weight of the vehicle but also must carry axial load when the car turns right or left. The bearings need to keep the wheel from sliding left or right off the axle. Tapered roller bearings are commonly used in this application and are frequently referred to as "Timken" bearings, after one of the first companies that designed and manufactured automotive tapered roller bearings. Figure 3's tapered roller bearing image shows the taper of the rolling element and the angular contact of the races with the rolling elements. Looking at the orientation of the image, one can see that the bearing would not allow the outer race to move axially from right to left. However, a force from left to right would separate the bearing. Therefore, two of these type of bearings are placed on the steer axle, one to handle thrust to the right and the other to handle thrust to the left, keeping the wheel on the shaft.

Roller bearings in general have greater load carrying capacity than ball bearings.

The ball bearing in Figure 3 also can handle some axial load due to the opposing "lips" of the inner and outer race. This particular configuration would resist a left to right thrust on the outer race. The barrel roller bearing also can resist some axial thrust. Neither of these will resist a great deal of axial load as the edges on the races will wear more rapidly and eventually fail. Needle and cylindrical roller bearings are used in radial load applications only—no axial load.

A side note on barrel roller bearings is, because of the shape of the rollers and the outer race, they can handle slight shaft misalignment without damage. These double row barrel roller bearings are common in the paper making industry. The bearings can withstand slight flexing of the large drying rolls suspended within the paper machine.

Now let's get back to axial thrust loads. Helical gears and turbines produce significant axial loads. *Thrust bearings* are commonly used in these, and other applications that generate thrust loads, to keep the rotating shafts in place. Thrust bearings do not support any radial load. The races are orientated 90 degrees to the races of radial load bearings *(see Figure 4 on page 42)*. Another type of thrust bearing used in many turbine applications is the tilting pad thrust bearing. The tilting pad thrust bearing uses tilting pads to develop an oil film wedge against a thrust collar to resist the axial load versus rolling elements.

Let's review some of the variables that affect lubricant choice for various bearings, such as temperature, speed, load and system design.

The system design usually dictates whether to use grease or oil in journal and rolling element bearings. Some advantages of grease lubricated bearings are a less

expensive design, less leakage from the bearing requiring less lubricant, less lubricant is squeezed out of the lubrication zone when the unit is shut down, thus, providing lubricant film almost immediately at system startup reducing wear and grease acts as a sealant to keep out dirt, dust, water and other environmental contaminants. Disadvantages of grease are it does not remove heat from the bearing and there are limits to effectiveness under high speed and load conditions. The April 2022 TLT Lubrication Fundamentals article titled "Regrease properly" discusses quantities and frequency of regreasing journal and rolling element bearings. Lubricant cleanliness and purging of the bearings also were discussed.

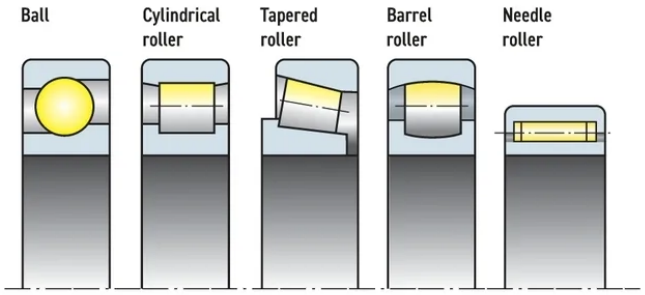


Figure 3. **Various rolling element types.**

Journal bearing design may include grooves extending from the point of oil or grease lubricant entry to distribute the lubricant across the width of the bearing. Different groove patterns are utilized depending on the bearing application and the application of the lubricant. Some bearings only have grooving in the upper half of the bearing or away from the load carrying zone of the bearing. Other bearings may have grooving throughout the internal circumference of the bearing. However, it should be noted that grooves in the bearing load zones reduce the load carrying capacity, which is taken into consideration when sizing the bearing and recommending the right oil viscosity.

High speed, heavy loads and high temperatures in steam and gas turbines dictate the use of oil versus grease. Most of these turbines utilize journal bearings and have a lubricant circulation system to supply lubricant to the bearings. The circulating lubricant helps keep the bearings relatively cool. The lubricant circulation also removes contamination from the bearings. When the turbine is up to operating speed and temperature, the bearing lubrication is in the hydrodynamic lubrication regime or full fluid film lubrication. This was covered in the July 2022 TLT Lubrication Fundamentals article titled "The Stribeck curve."

Oil viscosity requirements for journal bearings vary from as low as 12 centistokes (cSt) to as high as 350 cSt at operating temperature, all depending on the journal speed, or revolutions per minute (rpm), and whether the load is steady and moderate. If the bearing is heavily loaded or is expected to experience shock loads, another speed versus viscosity curve is used to determine an ideal, slightly higher viscosity than with the steady and moderate load. The recommended minimum operating temperature viscosity is then used on an ISO viscosity grade (VG) temperature versus viscosity chart to determine what ISO VG has the minimum viscosity at the system operating temperature to achieve hydrodynamic lubrication. This usually occurs when the lambda ratio reaches 3, or the lubricant film thickness is three times the combined root mean square of the surface roughness of the bearing and journal. The ISO VG calculation also can be used to determine what oil ISO VG in a grease to use in slower journal bearings where grease may be used.

Now, let's consider the lubrication regime of turbine bearings at startup, well below the rpms required to reach hydrodynamic lubrication. Many turbine lubrication systems utilize hydrostatic lubrication to separate the journal from the bearing during the startup of the turbine providing enough oil to produce a mixed-lubrication regime before a full fluid can be established. At startup, an oil pump generates oil flow into the bottom of the bearing to the grooves in the bearing and lift the journal off the bearing surface. Once hydrodynamic lubrication is achieved the hydrostatic pump is no longer required to maintain a lubricant film, a full fluid film.

Automotive engine bearings also are lubricated via circulation system; however, they are not hydrostatically lubricated before the engine starts. The automotive bearings rely on residual engine oil in the bearing and antiwear additives to protect the bearings during startup.

Journals float on an area of lubricant film due to the conforming surface of the bearing to the journal. Rolling element bearings have a point of contact between the ball rolling elements and the raceways, and a line of contact between the rollers and raceways. In both cases, these are non-conforming surfaces and are key to developing an elastohydrodynamic (EHD) lubrication regime. The pressures exerted on the bearing races and rolling elements are in the range of 30,000 psi, which deforms the metals instantaneously and momentarily traps the oil in the contact zone. Under these pressures the oil's viscosity also momentarily increases the oil's viscosity exponentially to separate the rolling element from the race. EHD lubrication calculations involve surface roughness, rolling element type, temperature and speed to determine the proper ISO VG. EHD lubrication is a complex subject that we will have to address in another article.

The type of rolling element and the cage that maintains the elements positions dictate the maximum speed a bearing may run safely. Both bearing size and rpm determine the actual speed of the rolling elements of the bearing. Therefore, bearing OEMs utilize the "NDm" factor, or value, to express the maximum ▶

Figure 4. **Thrust bearing.**

operating range for the bearing. The NDm factor also offers a general guide to maximum factor allowed for oil and for grease lubrication *(see Table 1)*.

The NDm factor equation essentially takes the pitch circle, or average diameter of the bearing race diameters, times the rpms to determine the factor.

Table 1. **Maximum NDm factors for lubrication**

Bearing type	Oil lubricated	Grease lubricated
Radial ball bearings	500,000	340,000
Cylindrical roller bearings	500,000	300,000
Ball and roller thrust bearings	280,000	140,000

The NDm factor is a product of bearing rpms (n) times the sum of the inner race bore (d) and the outer race outside diameter (D) in millimeters, all divided by 2, or NDm = n(d + D)/2.

The DN factor, perhaps a predecessor to the NDm factor, only utilized the inner race bore in millimeters times the rpm to get the DN factor. Most rolling element bearing OEMs have stopped using the DN factor in favor of the NDm factor, because of the wide rolling element size variations.

Rolling element bearings require significantly less oil than journal bearings. This is partially why greased rolling element bearings can go so long between regreasing. The rolling elements push the grease out of the way of the rolling elements just enough to not interfere with the rolling elements but not so far as to not contact each other. The rolling elements continue to swipe against the grease, wicking just enough oil to lubricate the bearing. Interestingly, high speed rolling element bearings require low oil viscosity, as expected, but they work better with a stiffer, or higher NLGI grade, grease (see the May 2022 TLT Lubrication Fundamentals article titled "Grease fundamentals: What color grease is best?"). The stiffer grease does not slump back into the path of the rolling elements, which would cause additional resistance in the bearing and overheating.

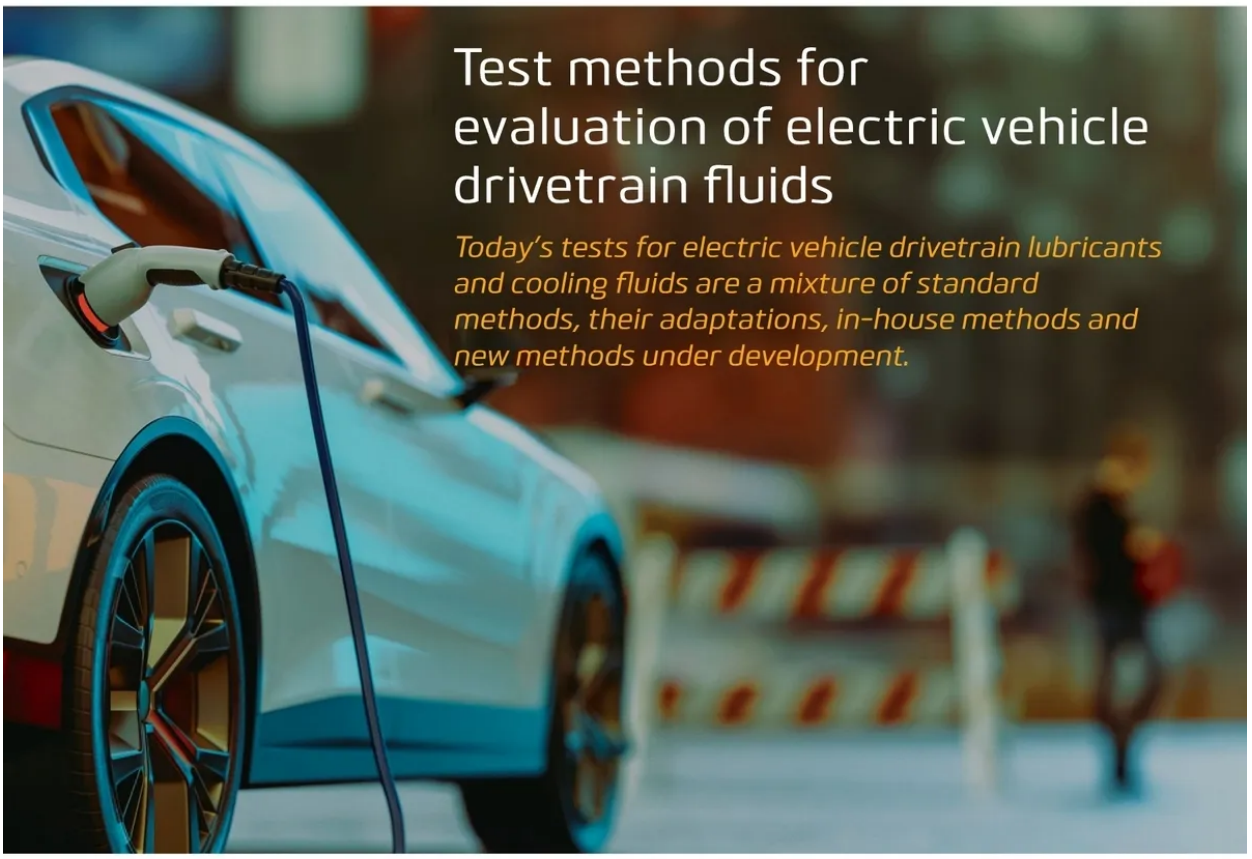
Using the right lubricant and the application of it, the bearing may last the lifetime of the equipment.

Similarly, oil baths, whether maintained via a bottle oiler, oil baths or oil circulation system, can cause extra internal friction. The oil level should only be up to midway of the bottom rolling element. This provides enough lubricant to protect the bearing but not so much as to cause interference in the rolling of the elements and overheating. More oil is not necessarily better.

Bearings are often designed to be "sacrificial" to protect more critical components of a system or machine. However, with today's higher performing lubricants and better metallurgy, using the right lubricant and the application of it, the bearing may last the lifetime of the equipment. In fact, more bearings are "packed for life" with long-lasting lubricants, never needing relubrication. As the name implies, packed-for-life bearings are expected to last the life of the equipment.

Dan Holdmeyer is retired from Chevron Lubricants and is based in Washington, Mo. You can reach him at ***dan.holdmeyer@gmail.com****.*

WEBINAR



Test methods for evaluation of electric vehicle drivetrain fluids

Today's tests for electric vehicle drivetrain lubricants and cooling fluids are a mixture of standard methods, their adaptations, in-house methods and new methods under development.

By Dr. Nancy McGuire
Senior Feature Writer

KEY CONCEPTS

Electric vehicle drive units run under different conditions than their internal combustion counterparts, and tests must be created and adapted accordingly.

Electric vehicle fluid formulations are as varied as vehicle designs, and both are evolving rapidly.

As electric vehicles continue to mature, the industry needs repeatable test methods that can differentiate lubricants while maintaining strong ties to field performance to ensure that those methods are relevant to the application.

Today's electric vehicles (EVs) encompass a wide variety of architectures and designs. Discussions of lubricants for EVs can include fully electric vehicles, as well as conventional hybrids, plug-in hybrids and fuel cell vehicles. Each design places unique demands on its lubricants. For the near future, at least, there is no one-size-fits-all lubricant solution. Often, a change to improve performance in one area can reduce performance in another area, so a delicate balance is required for the lubricant to meet a specific application. Even though EV lubricants are highly customized, producing useful and meaningful test results requires repeatable test methods for comparing formulations and evaluating their performance.

This article is based on an STLE webinar titled Test Methods for Evaluation of Electric Vehicles, presented by STLE member Rebecca Warden, senior research engineer for Chevron Oronite. See Meet the Presenter for more information.

Lubricant formulation for conventional applications is a relatively mature field. A variety of standardized tests and established acceptable ranges for test results help yield good field performance. In contrast, there are few standardized tests specific for EV fluids. Some tests developed for conventional vehicle applications or for other mechanical systems may be

tangentially applicable, but there is little consensus about how relevant those tests are to EV applications and how they correlate to long-term field performance. What EV drivetrain fluid properties require testing, and what is the current state of the art?

Producing useful and meaningful test results requires repeatable test methods for comparing formulations and evaluating their performance.

Electrical properties

A lubricant's base oil and additive package determine its electrical properties and how it interacts with an electric field, which, in turn, can affect the fluid's performance. These interactions change as the fluid shears, oxidizes or is contaminated with wear particles or water. Testing a fluid's electrical properties in a way that is relevant to the end application requires considering operational conditions like voltage level and frequency, test temperature and levels of contamination.

Electrical conductivity is a key property of EV fluids. An EV fluid with conductivity that is too high can transmit stray currents, which in extreme cases can pose a safety hazard. On the other hand, if the fluid's conductivity is too low, static charges may build up and then discharge suddenly, damaging bearings and other components. The optimal range between "too high" and "too low" has yet to be established.

Several methods exist for testing the electrical conductivity (or its inverse, resistivity) of transformer oils, which also are insulating fluids. For this reason, ASTM D1169 is a good place to start when evaluating EV fluid conductivity *(see Electrical Properties)*. In this test, the lubricant sample provides the only interface between two concentric electrodes, one grounded and another with an applied voltage. The amount of induced current traveling between electrodes indicates the fluid's conductivity *(see Figure 1 on page 46)*. This method is applicable to DC currents (it does not address AC frequency), and it covers a limited range of temperatures. A new method in development, DIN 51 111, will evaluate a fluid for conductivity, relative permittivity and dissipation factor with an AC current. Benefits of this new method over ASTM D1169 are the low fluid volume required for testing, the expanded temperature evaluation range and the use of AC instead of DC voltage.

Some EV designs place high demands on insulating fluids. For example, it can be important to evaluate a formulation's ability to resist dielectric breakdown under high voltages. Dielectric breakdown testing evaluates a lubricant's ability to withstand applied electrical stress by increasing the voltage between two electrodes until an electrical arc passes through the insulating fluid in between. ASTM D1816 uses a button-style electrode *(see Figure 2 on page 46)*, while other methods use the same principles with different electrode shapes and styles. Existing tests are limited to AC currents in the 45- to 60-Hertz range and ambient temperature; however, typical EVs operate at much higher switching frequencies and temperatures.

The power factor, related to the dissipation factor, is an indication of the fluid's dielectric losses in an AC electric field. This can be correlated to an increase in

Meet the Presenter

This article is based on a webinar presented by STLE Education on Feb. 16, 2022. **Test Methods for Evaluation of Electric Vehicles** is available at **www.stle.org:** $39 to STLE members, $59 for all others. This article contains information that has been updated from the webinar to reflect changes in this rapidly evolving field.

Rebecca Warden

STLE member Rebecca Warden is a senior research engineer at Chevron Oronite, functioning as a test engineer and OEM liaison for driveline and hydraulics, with a focus on lubricant additive development for next-generation electric vehicles. Prior to joining Chevron Oronite, Warden was the manager of advanced drivetrain lubricants at Southwest Research Institute (SwRI), focusing on lubricant evaluations for electrified vehicles, automatic transmissions, axles, tractor hydraulic systems and gear/hydraulic systems in industrial applications. Warden has been active for nearly 14 years in the lubricants industry with over a decade of experience in driveline testing.

You can reach her at ***Rebecca.Warden@chevron.com***.

Electrical properties

ASTM D1169 Standard Test Method for Specific Resistance (Resistivity) of Electrical Insulating Liquids **(www.astm.org/d1169-11.html)**

DIN 51 111 (draft status) Electrical properties of fresh and used oils from electric drives in vehicles **(www.din.de/en/getting-involved/standards-committees/nmp/drafts/wdc-beuth:din21:364582829)**

ASTM D1816 Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes **(www.astm.org/d1816-12r19.html)**

ASTM D924 Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids **(www.astm.org/d0924-15.html)**

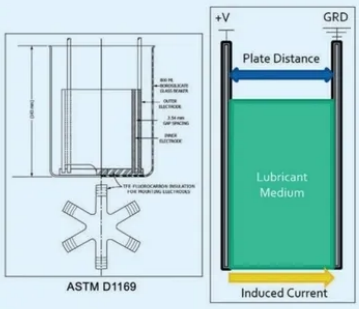


Figure 1. **Setup for ASTM standard tests D1169 (resistivity) and D924 (dissipation and relative permittivity).** *Left side of the figure courtesy of ASTM D1169.*

lubricant temperature due to lost power. The power factor is expressed as the ratio between the true power (the power available to do useful work) and the apparent power (the power that would be available if there were no dielectric losses).

For electrically insulating fluids, including EV fluids, ASTM D924 is the standard test method for dissipation factor (or power factor) and relative permittivity (dielectric constant). This method applies to AC frequencies from 45 to 65 hertz, much lower than a typical EV's operating range. The test cell design for D924 is the same as for method D1169, with a fixed electrode spacing and a limited temperature range. The temperature limitations of existing standardized tests are especially relevant because some EV fluids serve as coolants as well as lubricants. Power loss often manifests itself in the form of heat generation, and keeping power losses as low as possible is highly desirable.

High-speed EV gears and bearings are prone to wear and unique failure mechanisms. For example, stray electrical currents from the motor can ground through a bearing, which causes a rippling effect called fluting. This decreases the bearing's life and causes noise and vibration problems. OEMs are working to reduce the chance of fluting by ensuring that electrical grounding paths do not go through bearings. Ceramic bearing components are an effective, but expensive, solution. Grounding rings, another solution, can wear out and become ineffective over time. Each of these mechanical design solutions adds to the cost of designing and manufacturing an EV.

Using more conductive lubricants could be a solution, but EV-relevant lubricant tests need to be developed. A new method, currently under development to evaluate a lubricant's ability to prevent this type of damage, uses a rotating motor to induce currents that are grounded through a test bearing. This method operates at speeds up to 4,000 rpm, loads as high as 2.4 kN, under peak-to-peak voltages as high as 60 V, while controlling lubricant temperature between 20 C and 100 C.

Heat transfer

Heat transfer is another important property of EV fluids, especially those used for EV motor cooling applications. Thermal conductivity, diffusivity (the rate of heat transfer from a material's hot end to its cold end) and specific heat capacity (the quantity of heat absorbed per unit mass per unit temperature rise) are all used to define a material's ability to store and transfer heat. These three properties can be measured using ASTM D7896 *(see Heat Transfer and Materials Compatibility)*. This method, originally developed for engine coolants, uses a thin platinum wire immersed in the sample. A pulse of current passes through the wire, which heats the wire and the fluid sample, and the resistance of the wire is measured as it cools. The profile of fluid temperature versus time is an indicator of the fluid's thermal properties. The standard method is applicable in the temperature range between -20 C and 100 C.

Convective heat transfer encompasses all of the lubricant properties of a fluid that can affect the ability of that fluid to transfer heat away from the electric motor. It can be measured directly using a forced convection calorimeter. Oil is circulated through the calorimeter at a specified flow rate, as well as specified wall and fluid temperatures. Heat is applied to the test section to maintain a consistent wall temperature, and the fluid temperature increase is measured across the test section.

Materials compatibility

EV fluids must be able to avoid damaging or being significantly degraded by the metals, polymers or other materials with which they are in contact. Copper corrosion, both immersed and in the vapor space, is one major concern of fluid developers. Copper corrosion not only removes copper from the wiring, but it also forms conductive deposits on various components of the system, both of which can cause catastrophic damage.

Figure 2. **Dielectric breakdown testing apparatus with button electrodes.** *Figure courtesy of Chevron Oronite.*

A new wire corrosion test has been proposed to ASTM for consideration as a standard method. This 70-hour test uses 400-ml fluid samples heated to between 80 C and 150 C. A small current passes through 1 meter of 64-micrometer diameter wire that is either immersed in the fluid or suspended in the vapor space above the hot lubricant. As copper corrodes away from the wire, the rate of electrical resistance increases, and this can be correlated to the wire's diameter changes.

Additionally, work has been done to develop EV-specific adaptations to the

copper corrosion test method ASTM D130 *(see Heat Transfer and Materials Compatibility)*. In this test, a polished copper strip is immersed in the sample and/or exposed to the vapor space and heated for a specified amount of time. Then, the copper strip is removed, washed and rated by comparing it to a set of standard degraded copper strips. The test is typically run for three hours at 150 C for conventional automatic transmission fluid applications *(see Figure 3)*. Adapting this method to EV fluids requires extended test durations, including vapor phase exposure and analyzing the copper content of the oil in which the test sample has been submerged.

Conductive deposit tests use stacked circuit boards that are exposed to the oil and vapor phases during testing. Conductive deposits form, causing electrical shorts between the boards. The change in electrical resistance over time indicates the formation of conductive deposits shorting the electrical path. Currently, tests can last as long as 1,000 hours.

Polymer products are another area of concern for compatibility. These include structural plastics, wire insulation materials and new plastics that are not commonly used in other applications. Exposure to lubricants can affect polymer swelling, hardness and tensile strength. ASTM D638 is a tensile test method that can be applied after a structural plastic is exposed to a lubricant *(see Figure 4 on page 48)*. To ensure this test is relevant, the EV OEM must determine how long to expose plastics and polymers to the test lubricant, what test temperatures best correlate to actual field conditions and what materials are most representative of those in their EVs.

Motor winding coatings are another area where standardized testing is being investigated, and these tests are still very new. These coatings, typically polymer materials, insulate the motor windings, preventing short circuits and motor failures. Corrosion of the polymer coatings can be evaluated by looking at the breakthrough voltage: the voltage level required to break through the coating to the bare copper below. In one test, coated copper wire "hairpin" samples (a u-shape with the center submerged in the fluid and the ends protruding above the fluid) are aged in a

Heat transfer and materials compatibility

ASTM D7896 Standard Test Method for Thermal Conductivity, Thermal Diffusivity, and Volumetric Heat Capacity of Engine Coolants and Related Fluids by Transient Hot Wire Liquid Thermal Conductivity Method **(www.astm.org/d7896-19.html)**

ASTM D130 Standard Test Method for Corrosiveness to Copper from Petroleum Products by Copper Strip Test **(www.astm.org/standards/d130)**

ASTM D638 Standard Test Method for Tensile Properties of Plastics **(www.astm.org/d0638-14.html)**

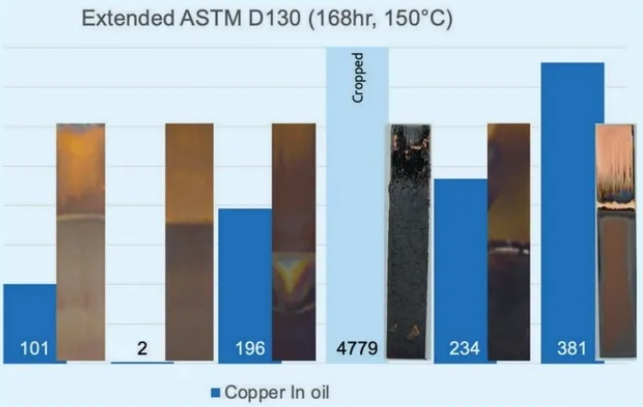


Figure 3. **Extended-duration adaptation of ASTM D130 copper corrosion test. Blue bars show final concentrations of copper in the oil sample (parts per million).**
Figure courtesy of Chevron Oronite.

Color chart for ASTM D130 copper corrosion test.
Figure courtesy of Airman 1st Class Greg Erwin, U.S. Air Force.

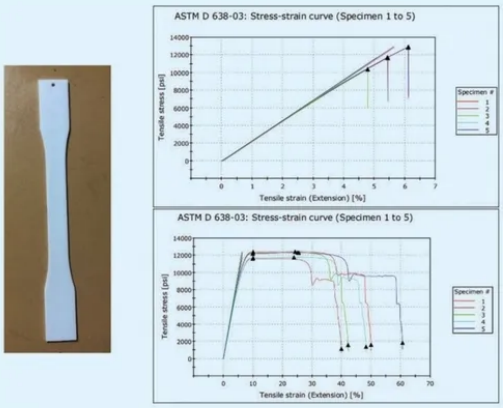


Figure 4. **"Dog-bone" polymer sample (left) for ASTM D638 and two types of tensile failure (right).** *Figure courtesy of Southwest Research Institute.*

test fluid at a defined temperature (static or dynamic) for a defined duration. At the end of the test, the coatings are evaluated for breakthrough voltage.

Oxidation and aeration

Oxidation performance tests are a given for any type of vehicle fluid, but the oxidation mechanisms in EVs are likely different than the mechanisms evaluated using today's standard test methods. Lubricants are often sprayed or dripped onto hot EV motor windings or circulated through the motor itself. The temperatures at the fluid–hardware interfaces are relatively high compared to the sump temperature of the fluid. Sump volumes are relatively low, making oxidation control critical.

Although ASTM has no applicable standard methods for this EV-specific situation, several other commonly used tests can provide useful information. These include the ABOT (BJ 110-04), DKA (CEC L-48), L-60-1 (ASTM D5704) and ISOT (JIS K 2514), among others (*see Oxidation and Aeration)*. However, each of these methods uses very high bulk fluid temperatures instead of the high interface temperatures typically seen in EV applications.

The ABOT (aluminum beaker oxidation test, BJ 110-04), developed for automatic transmission fluids, uses lead, aluminum and copper test coupons *(see Figure 5 on page 50)*. The test results include viscosity change, pentane insolubles, acid number change, infrared (IR) change, elemental analysis, copper coupon rating, lead coupon weight loss, aluminum strip rating and sludge rating. The DKA method, also commonly used for automatic transmission fluids, tracks changes in viscosity, acid number, IR spectrum and sludge rating. Reported results also include end-of-test flask photos to characterize any deposits generated in the glassware and a blotter evaluation to characterize fluid cleanliness.

The ASTM D5704 (L60-1) method was developed for automotive gear lubricant evaluations. This method looks at changes in viscosity, pentane and toluene insolubles and the formation of sludge and carbon varnish deposits. The Indiana stirring oxidation test (ISOT), developed for internal combustion engines, uses steel, a copper catalyst and a glass varnish stick immersed in fluid to evaluate varnish deposits. This test tracks changes in acid number and viscosity, as well as a glass varnish stick rating.

Fluid aeration can facilitate oxidation, and it also can affect heat transfer and gear protection as well as increase churning losses. Several test methods assess foaming performance, including ISO 12152 and ASTM methods D3427 and D892, along with proprietary and in-house test methods. Foaming can be different from aeration (air entrained within the fluid), but it is just as important to EV performance.

The most current aeration test methods in driveline applications aerate the lubricant very differently than what is seen in EV applications. EV motors run at very high speeds, which increases aeration—in one EV motor fluid aeration test

Oxidation and aeration

ABOT (BJ110-04), Aluminum beaker oxidation test (e.g., **http://doi.org/10.4271/2001-01-1991**)

CEC L-48 **(http://cectests.org/assets/presentations_publications/cec14_3255_3.pdf)**, DKA modification (e.g., **http://doi.org/10.4271/2014-01-2801**)

ASTM D5704 (L-60-1) Standard Test Method for Evaluation of the Thermal and Oxidative Stability of Lubricating Oils Used for Manual Transmissions and Final Drive Axles **(www.astm.org/d5704-22.html)**

ISOT (JIS K 2514), Indiana stirring oxidation test. Lubricating oils-Determination of oxidation stability - Part 1: Oxidation stability of internal combustion engine oils **(http://infostore.saiglobal.com/en-us/standards/jis-k-2514-1-2013-633384_saig_jsa_jsa_1452587/)**

ISO 12152 Lubricants, industrial oils and related products—Determination of the foaming and air release properties of industrial gear oils using a spur gear test rig—Flender foam test procedure **(http://webstore.ansi.org/standards/iso/iso121522012)**

ASTM D3427 Standard Test Method for Air Release Properties of Hydrocarbon Based Oils **(www.astm.org/d3427-19.html)**

ASTM D892 foam test Standard Test Method for Foaming Characteristics of Lubricating Oils **(www.astm.org/d0892-18e01.html)**

operating at up to 17,500 rpm, the aeration level reached almost 25% (75% fluid, 25% air). One example of a high-speed aeration evaluation involves pumping a lubricant from the sump of an electric drive unit through a gas content monitor to evaluate the degree of aeration under a specified set of operating conditions *(see Figure 6)*.

Wear and failure

Today's EVs have motors operating at 18,000 to 20,000 rpm, and manufacturers are considering taking this significantly higher—possibly up to 50,000 rpm. Today's standardized gear and bearing tests were not designed with these extreme speed requirements in mind. Historically, the industry has relied heavily on FZG gear testing methods to evaluate different forms of gear wear.

Wear and failure

DIN-ISO-14635-2 | Part 2: FZG Step Load Test a10/16, 6R/120 for Relative Scuffing Load-Carrying Capacity **(www.document-center.com/standards/show/DIN-ISO-14635-2)**

DIN 51 819-3 (D-7.5/80-80), Testing of lubricants: mechanical-dynamic testing in the roller bearing test apparatus **(http://infostore.saiglobal.com/en-us/standards/din-51819-3-2016-12-421785_saig_din_din_953757/)**

For example, the FZG a10/16.6R/90 step load method can be used to assess extreme scuffing prevention *(see Wear and Failure)*. Scuffing is the instantaneous welding and release that happens when there is direct metal-to-metal contact. This type of damage occurs when the lubricant is unable to prevent metal-to-metal contact between gear teeth. The test method increases the load on the gears until scuffing occurs. Additional FZG test methods can be used to assess pitting, micropitting and wear.

Just as important as protecting the gears, the lubricant also must properly protect the bearings from damage and wear. To date, there are no standardized high-speed bearing tests, but historical tests can be used to assess a lubricant's ability to appropriately protect the bearings. The DIN 51 819-3 (D-7.5/80-80) test evaluates the lubricant's ability to prevent wear on the bearing rollers.

Figure 5. **Setup for aluminum beaker oxidation test (ABOT).** *Figure courtesy of Southwest Research Institute.*

Battery coolants

There is significant potential for improvements in the area of direct liquid battery coolants. In a typical EV battery configuration, the cells sit on top of a cold plate, with a water-glycol solution passing underneath. However, in direct liquid battery cooled systems, the coolant passes directly between the battery cells, creating an interface between the fluid and the cells *(see Figure 7)*. The result is more effective heat transfer, which improves charging and discharging performance, potentially preventing fire propagation in the event of a battery cell failure. However, coolants must be compatible with batteries and their packaging materials.

Factors to consider in fluid formulations include the fluid's ability to remove heat from the battery cells while resisting combustion. Can the fluid mitigate or reduce thermal propagation and thermal runaway? Does the fluid keep the battery cooler? Does it increase the number of charge and discharge cycles? Can the battery be charged or discharged more rapidly? A fluid's fire resistance is a major concern: if one battery cell fails and goes into thermal runaway, it may catch fire. If the fire spreads to adjacent cells, the entire battery pack may ignite.

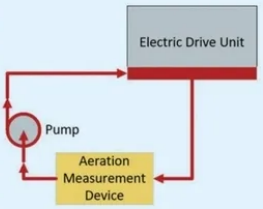


Figure 6. **Gas content monitoring of fluid aeration under high-speed operating conditions.**

Nail penetration tests simulate battery failure. For this type of testing, battery cells are fully charged at ambient conditions. Thermocouples are attached to each cell, and the battery is immersed in a circulating fluid maintained at a temperature typical of vehicle operating conditions. A nail is driven through one cell to see if it starts a fire and whether the fire spreads to nearby cells. Heat-induced failure testing involves a similar setup to the nail penetration test, but it uses a heater wire placed amongst the cells in a battery module. After the battery cells are fully charged under ambient conditions, the heater wire is energized and the ability of the coolant fluid to prevent and contain thermal runaway is assessed.

Battery life and performance testing involves placing a battery module and a container with the direct liquid battery coolant into a test chamber plumbed to a circulation system. The battery pack is wired to a battery cycling device in order to create an accelerated aging profile *(see Figure 8 on page 52)*. This method can be used for comparing various batteries and fluids to see how they perform.

Life testing involves repeatedly running a fast charge/discharge profile to accelerate aging under high stress. Every five days, the test module is compared to a baseline performance test to assess the

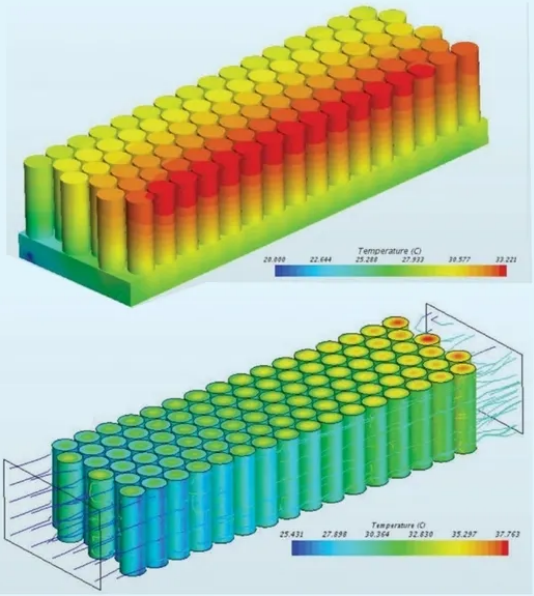


Figure 7. **EV battery cooling using a cold plate system (top) and direct cooling of the cells (bottom).** *Figure courtesy of Moghaddam, H. and Mazyar, S. (2018), "Designing battery thermal management systems (BTMS) for cylindrical Lithium-ion battery modules using CFD," KTH, School of Industrial Engineering and Management (ITM), Energy Technology, Independent Thesis, Advanced level. Available at* ***https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-244459****.*

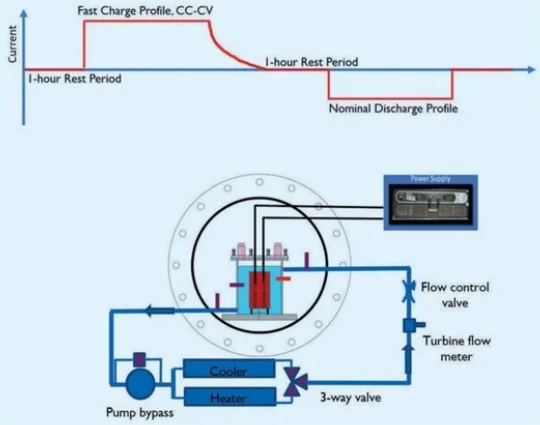


Figure 8. **Battery performance and life testing charge/discharge profile (top) and test setup (bottom).** *Figure courtesy of Southwest Research Institute.*

battery state of health and determine the effect of the direct liquid battery cooling to extend the life of the battery.

Performance testing targets a temperature rise on the fast charge profile, which helps to set limits on how fast a vehicle can be charged safely. The ability of the coolant to maintain the battery's temperature within acceptable limits during faster charging is measured. If the charging speed is increased and the temperature rises above an acceptable limit, the chances of battery degradation and failure are increased. Cooling performance during battery discharging also is important, especially for large vehicles and heavy-duty applications.

A work in progress

Although EV designs are currently robust enough for EVs to be sold as consumer products across all sectors (passenger cars, commercial applications and off-road applications), the field is still in its infancy. At present, the number of EVs in operation is still very small compared with the number of internal combustion engine vehicles on the road.

Because EV drive unit design is not a mature field, future EVs may look much different than today's models, so test methods for EV fluids must be developed to be forward looking. Several standardized test methods are under development, and some are now under ASTM and DIN evaluation. The degree and urgency of industry demand for standardization will play a significant role in the types of methods that are developed and how quickly this effort moves ahead.

The key for any standardized test method is to ensure that it is not only repeatable and able to differentiate between different lubricants, but also that it strongly correlates to field performance. Lubricant formulators need good tools to enable them to determine if a formulation change is providing the desired benefit in that performance attribute as well as not affecting the formulation negatively in other performance requirements. We expect to see significant developments in new EV-specific lubricant tests in the coming years that will help enable the development of superior lubricants, which, in turn, will help further the implementation of EVs.

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The end of PFAS

With the current phasing out and probable end of most PFAS applications, time is running out to come up with replacement lubricants and associated products.

By Jeanna Van Rensselar
Senior Feature Writer

PFAS are perfluoroalkyl and polyfluoralkyl substances that refer to a wide range of organic and inorganic chemicals containing at least one fully fluorinated carbon atom and that have radically different physical, chemical and biological characteristics. Due to their distinct chemical profile and desirable properties, such as high thermal stability, low surface tension and resistance to degradation, PFAS have been extensively used in the lubricants industry.[1]

KEY CONCEPTS

Materials containing PFAS have been damaging the environment for more than 80 years and, because they are highly persistent, they continue to accumulate in soil and waterways.

Restrictions on the introduction of new products containing PFAS are tightening in the U.S. and EU.

Because PFAS have a combination of properties that are especially beneficial for lubricants, suitable replacements will be difficult to develop.

PFAS have proliferated since they were introduced in the 1940s. There are now up to 10,000 different PFAS, more than 200 primary usage categories and countless subcategories.

In addition to industrial applications such as lubricants, seals and elastomers, textile treatments, firefighting foam and electroplating, consumer use categories include PFAS in ammunition, climbing ropes, guitar strings, artificial turf and soil remediation.[2] PFAS are present in some form in virtually all industries and a wide range of consumer goods.

They are everywhere, and they aren't going anywhere.

However, recent regulatory scrutiny in the U.S. and Europe and resulting/pending revisions that limit the use of PFAS in a variety of applications, including lubricants, are a result of growing public awareness of the harmful effects that highly persistent PFAS have on the environment and human health. There also is a lack of understanding about the characteristics, applications and toxicological profiles of many PFAS.

While PFAS could simply be removed from non-essential applications without

the need to first locate suitable replacements, regulation becomes complicated and substitution difficult for some crucial applications—such as health and safety—with no alternative formulations. This makes a blanket ban on all PFAS unrealistic.

> PFAS are present in some form in virtually all industries and a wide range of consumer goods. They are everywhere, and they aren't going anywhere.

Despite this, the lubricants industry will be impacted by these regulatory developments; alternatives that address environmental issues while delivering similar or better performance will be required—and soon.

Environmental impact

PFAS have long been an environment concern because they do not break down in the environment, they can migrate through soil and contaminate sources used for drinking water *(see PFAS Contamination in Water on page 58)*, and they bioaccumulate in fish and wildlife.

Uncertainty surrounds the consequences of PFAS exposure at low ambient concentrations on human health. Some PFAS may have an impact on growth and development, according to studies done on lab animals who received high doses of PFAS. These animal studies also suggest PFAS may harm the liver and have an impact on immune system, thyroid and reproductive functions.[3]

STLE member Dr. Amanda W. Stubbs, scientist group leader of tribology and industrial specialty greases, Nye Lubricants, Inc. (member of the FUCHS Group), explains, "Many of the alternatives we are considering are based upon existing PFAS-free technologies with known profiles offering improved sustainability and environmental responsibility over traditional PFAS-containing solutions. When evaluating novel technologies, we partner closely with our product stewardship team to do a thorough review of regulatory profiles to ensure that we are moving in a more sustainable and environmentally friendly direction."

Stubbs adds that, when working to develop alternative technologies meeting the most challenging technical requirements (for example, a lubricant with vacuum stability, high temperature performance and chemical inertness), the risk of making a lateral move in terms of sustainability and environmental friendliness is higher, due to the inherent nature of lubricant solutions that have these properties. "For example, materials that are chemically inert are going to be resistant to degradation and will pose a risk for bioaccumulation," she says.

Monitoring and restriction

STLE member Khalid Malik, CLS, OMA I and II, lead auditor general, nuclear oversight, Ontario Power Generation, observes that there is currently legislation and regulatory activities that are ongoing in the U.S. at a state and national level, and in the European Union through REACH[4] to classify fluoroelastomers as PFAS (polyfluoroalkyl) compounds. This would include fluorocarbon (FKM), fluorosilicone (FVMQ), TFE/P and perfluoroelastomer (FFKM). "These are the famous seal materials used in varieties of sealing technologies," he points out *(see Fluoroelastomer Seals and the Concept of Essential Use on page 56)*.

> There is a lack of understanding about the characteristics, applications and toxicological profiles of many PFAS.

In addition to monitoring existing PFAS contamination, the U.S. Environmental Protection Agency (EPA) is currently reviewing and restricting new formulations and new uses for PFAS.[5]

The following is a summation of the EPA's goals for restriction:[6]

- Utilize and coordinate efforts under all applicable legal provisions in order to minimize exposure to PFAS during consumer and industrial applications and to manage and prevent PFAS contamination.
- Assign manufacturers, processors, distributors, importers, industrial and other important users, dischargers and treatment and disposal facilities responsibilities for reducing exposures and managing PFAS dangers.
- Create programs that are voluntary to decrease the usage and release of PFAS.
- Regardless of socioeconomic status, racial identity or linguistic obstacles, prevent or reduce PFAS discharges and emissions in all communities.

The Netherlands, Germany, Sweden, Norway and Denmark are the authors and submitters of the REACH restriction proposal in Europe, which is designed to address the production, marketing (including import) and use of PFAS, including as constituents in other substances, mixtures and articles above a certain concentration in the EU.

With two different restriction options, the limitation proposal has a relatively broad scope (encompassing more than 10,000 PFAS chemicals). The two restriction options are:

1. A full ban after a transition period of 18 months.
2. Some instances of a phased ban, with specific time-restricted derogations applying for particular uses. This option also includes some time-unlimited derogations for exceptional cases. This is the preferred option and the most likely to be adopted.[7]

Jonatan Kleimark, senior chemicals and business advisor, ChemSec, The International Chemical Secretariat, clarifies, "So the proposal is comprehensive and covers all persistent PFAS substances, for all uses. There also are some general exemptions concerning pharmaceuticals, biocides and plant protection products. In addition, there are some derogations (time-limited exemptions) for specific uses, such as semiconductor manufacturing. For non-derogated uses, the transition time is 18 months, and for derogations it is either 6.5 or 13.5 years."

Kleimark says that the discussion, which ended Sept. 25, has been an opportunity for stakeholders to submit

information about PFAS uses, derogations, alternatives, etc. He adds, "After that, the European Chemicals Agency (ECHA) and its scientific committees form their opinion, which should be finished mid-2024. After that, the proposal will be on the Commission's table, with a decision sometime during 2025, hopefully, but it might be 2026. In summary, the restriction suggests a complete phase-out of PFAS over time."

Affected applications

There are many applications that could be impacted by PFAS regulation changes. Two important applications Malik cites are:

- Fluoroelastomers that are successfully used in phosphate ester (fire-resistant fluid) and fuel applications. Due to the fluoropolymer's ability to resist fire, weather, temperature and chemicals, these are the preferred elastomer and synthetic rubber compounds. Malik adds that other types of elastomers cannot withstand these conditions and have failed in service.
- Fluoroelastomers that are widely used in environmental qualifications (EQ) applications of nuclear plants. EQ is a procedure used to make sure that equipment will be able to survive any potential environmental conditions that may arise when it is actually required to carry out the intended function in accident-related circumstances. It often starts with testing that models design-based accident scenarios like loss of coolant accidents (LOCA), high energy line breaks (HELB) and severe accidents (SA). The testing then incorporates accelerated aging (thermal, radiation, vibration, mechanical) tests. The testing also must cover any other condition or combination of conditions that the component may have to operate in during design and beyond-design circumstances. "Many studies have been conducted on fluoroelastomer performance under severe thermal and radiation testing, and they have been proven much better than the other types of elastomers materials," Malik says.

Impact on the lubricants industry

Since the lubricants industry encompasses many other industries, industrial as well as consumer products, it will be important for this industry to identify alternatives and understand performance requirements at an early stage, Kleimark advises *(see The Urgent Need for PFAS Substitutes on page 59).*

"Especially important will be the understanding of performance requirements, since the PFAS-containing lubricants in many cases have much higher performance than is necessary for the use," he notes. "At the current time I don't see any readily available alternative for PFAS. I am not aware of any new emerging technologies, at least in my field. In fact, the industry is currently not prepared with any possible alternative. It might take some time to come up with suitable solutions, or there may be limited use of PFAS under strict criteria. The change should be scrutinized and not pose risks and problems to applications."

Dr. Lou A. Honary, president, Environmental Lubricants Manufacturing, Inc., explains that as a biobased grease and lubricant manufacturer, most of the issues with PFAS he deals with are related to the additives they use for performance enhancers in their products.

> The importance of developing PFAS-free replacements varies by industry and application.

"Since vegetable oils, which we use as base oils for our products, have shown to be free of per- and polyfluoroalkyl substances, the most important requirement within our industry is the ability of additive manufacturers to reduce or remove PFAS from their additives," he says. "Our concern is with the presence of PFAS in the additives we ▶

Fluoroelastomer seals and the concept of essential use

Khalid Malik, CLS, OMA I and II, lead auditor general, nuclear oversight, Ontario Power Generation, explains, "The notable advancement over the years in seal materials is in the use of fluoropolymer compounds. We tried different materials in the past, but none of them performed nearly as well as fluoropolymers. As far as I know, at the present time, there are no PFAS alternatives in the marketplace that offer the same high-performance levels and levels of safety."

Even though PFAS-containing fluoroelastomer seals are crucial to many industries, there are currently no alternatives in widespread use. These seals and other lubricant-related PFAS applications could be deemed by regulatory agencies "an essential use" meaning they may not be subject to the same regulatory scrutiny as other applications. The two qualifying elements of an essential use are:

1. That a use is necessary for health, safety or is critical for the functioning of society.
2. That there are no available technically and economically feasible alternatives.[A]

"There is need for a detailed study on new materials and their risks and challenges to applications and products in the long run," Malik says. "There should be some classification, specifying and naming hazardous and non-hazardous chemicals to support the seal industry."

A. Cousins, I.T., Goldenman, G., Herzke, D., Lohmann, R., Miller, M., Ng, C.A., Patton, S., Scheringer, M., Trier, X., Vierke, L., Wang, Z. and DeWitt, J.C. (2019), "The concept of essential use for determining when uses of PFASs can be phased out," *Environmental Science: Processes and Impact*, **11**. Available at: **https://pubs.rsc.org/en/content/articlelanding/2019/em/c9em00163h.**

purchase to enhance the performance of our biobased grease and lubricants. But, since we are certain vegetable oils do not contain PFAS in their natural forms, we have to rely on the expertise of the additive manufacturers to find replacements for PFAS in their products."

Stubbs adds that the importance of developing PFAS-free replacements varies by industry and application. "In some cases, a suitable PFAS-free solution is already available; customers moving to this technology will impact relative levels of demand, which may put a strain on the supply chain," she cautions. "In exploring new technologies to satisfy more technically challenging applications, I anticipate that new lubricants with novel properties will be innovated; some will satisfy existing PFAS-containing technology replacements, while others may enable us to accomplish things that were previously unattainable."

PFAS replacements

The advantages of PFAS materials in lubricants have been thoroughly studied, and certain studies have determined that the performance of PFAS-free technology can sometimes be equal to or even better than conventional technology, especially when it comes to low temperature characteristics, stick-slip behavior and wear resistance.

While the elimination of PFAS does provide certain technological hurdles in applications demanding high temperatures, chemical inertness and vacuum conditions, developers are now working on next-generation technologies.

"It is important to emphasize that requirements vary by application; one of our key strategies in developing alternative technologies is ensuring that we have a thorough understanding of customer applications and are utilizing appropriate test methods to screen for these properties in the lab," Stubbs says. "Field trials are and will continue to be a key part of our development process as well. As we explore alternative technologies, we are leveraging our supplier relationships."

Honary believes that, in principle, finding replacements for different types of per- and polyfluoroalkyl or fluorinated substances will not be difficult. But, he cautions, to replace all of the different fluorinated substances in a diverse array of products will require a long time as well as significant cost.

Stubbs explains, "While the regulatory landscape remains uncertain, we have been preparing for elimination of PFAS-containing lubricants. We recognize how challenging and costly (in time, energy, resources and funds) it can be for some customers, particularly OEMs, to change the identity of the lubricant in their application. Because of this, we are continuing to offer our existing PFAS-containing products but have made the decision to not formulate new products with fluorinated raw materials. Additionally, some customers looking to spec in new lubricants are actively choosing not to evaluate PFAS-containing options in the interest of avoiding future headaches if regulations ultimately limit the use of these products."

She continues, "We acknowledge that PFAS-free technologies will likely not be a one-size-fits-all solution. As we develop alternative technologies, we are performing extensive screening at the bench level, beginning with basic properties and going so far as to use custom application simulation test rigs that we have built in house. We are partnering closely with our product management team to ensure we have a thorough understanding of the variety of applications in which our products are used, so that we can perform appropriate

PFAS contamination in water

Dr. Lou A. Honary, president, Environmental Lubricants Manufacturing, Inc., observes that since one of the most troubling aspects of PFAS in human health is related to their presence in drinking water, the assumption would be that all applications near or on waterways or close to aquifers would require more immediate actions than others. He cites applications such as drilling where drill rod grease is introduced into the ground and wire ropes used in cranes or equipment for dredging.

According to a recent NPR blog post, there are several PFAS that are of particular concern in drinking water.[A] Research that includes a USGS study[B] has connected exposure to specific PFAS to harmful health effects in people, including an increased chance of developing certain malignancies, an increased risk of obesity and high cholesterol, a decreased ability to conceive children and developmental issues such as low birth weight.

The USGS study is the first to compare PFAS in tap water across the entire U.S. from both public and private sources.

A. Treisman, R. (July 6, 2023), "'Forever chemicals' could be in nearly half of U.S. tap water, a federal study finds." Available at: **www.npr.org/2023/07/06/1186230007/drinking-water-forever-chemicals-pfas-study**.

B. Smalling, K.L., Romanok, K.M., Bradley, P.M., Morriss, M.C., Gray, J.L., Kanagy, L.K., Gordon, S.E., Williams, B.M., Breitmeyer, S.E., Jones, D.K., DeCicco, L.A., Eagles-Smith, C.A. and Wagner, T. (2023), "Per- and polyfluoroalkyl substances (PFAS) in United States tapwater: Comparison of underserved private-well and public-supply exposures and associated health implications," *Environment International*, **178**, 108033, **https://doi.org/10.1016/j.envint.2023.108033**.

testing and target the most informative field trials for our new technologies."

Summary

Honary believes that the presence of PFAS in everyday products is so pervasive that it will require many years to even partially eliminate the chemical. "The polarity of vegetable oils is such that in many applications they bond to metal surfaces and lubricate without the need for antiwear or extreme pressure additives," he says. "As such the biobased lubricants industry has a starting advantage due to the use of renewable oils. While additives that contain PFAS are currently in use, it is likely that economical alternatives will be available. The cost to replace existing additive formulations and qualify products with the new PFAS-free additives will be expensive and could require decades to accomplish."

Stubbs summarizes, "This is an exciting time to be in the R&D field of the lubrication industry. Various challenges over the last few years, including the global COVID-19 pandemic, supply chain disruption and regulatory flux, have spurred exploration of new technologies and adoption of agile strategy. While the times have been challenging, I think in the long run we are going to benefit from what we have learned, and we will continue to learn over this period."

Kleimark concludes, "Since there may be a complete phase-out, all industry sectors will have to ensure that their supply chain is on top of this. The main obstacle for companies is to understand whether they are using PFAS, and how the potential uses can be identified. This is especially difficult for industrial uses, for example for the industrial use of lubricants."

The U.S. EPA also maintains a resource library for PFAS information and compliance.[8] Other resources are available through individual companies, trade organizations and action groups.[9, 10]

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The urgent need for PFAS substitutes[A]

The EU has started reviewing the new proposal for REACH[B] restriction of all per- and polyfluoroalkyl substances (PFAS). Following are four reasons to take action on PFAS substitutes now.

1. **There is a significant number of formulations.** According to a broad interpretation of the European Chemicals Agency (ECHA), PFAS affect more than 10,000 chemicals.
2. **Because of new and pending regulation, time is running out.** The limitation could ban the import and production of PFAS in Europe within 18 months of its implementation.
3. **Markets, including the lubricants market, have already been affected.** Massive changes have been announced by major stakeholders, and production methods for fluoropolymers (such as polytetrafluoroethylene, PTFE) have already been disrupted. Some companies are ceasing PFAS production as soon as 2025.
4. **End-users are actively looking for PFAS alternatives.** In recent months, PFAS-free materials have risen to the top five most sought-after additives.

A. Stoyanova, A. (June 6, 2023), "4 reasons why you must speed up the offering of PFAS substitutes," SpecialChem blog post. Available at **http://bit.ly/43jizTk**.

B. Registration, Evaluation, Authorisation and Restriction of Chemicals.

1. Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A. and van Leeuwen, S.P. (Oct. 2011), "Perfluoroalkyl and polyfluoroalkyl substances in the environment: terminology, classification, and origins," *Integr Environ Assess Manag*, **7** (4), pp. 513-41. doi: 10.1002/ieam.258. PMID: 21793199; PMCID: PMC3214619.
2. Glüge, J., Scheringer, M., Cousins, I.T., DeWitt, J.C., Goldenman, G., Herzke, D., Lohmann, R., Ng, C.A., Trier, X. and Wang, Z. (2020), "An overview of the uses of per- and polyfluoroalkyl substances (PFAS)," *Environ Sci Process Impacts*, **22** (12), pp. 2345-2373. doi: 10.1039/d0em00291g. Epub 2020 Oct 30. PMID: 33125022; PMCID: PMC7784712.
3. From CDC Fact Sheet: Per- and polyfluorinated substances (PFAS). Available at **www.cdc.gov/biomonitoring/PFAS_FactSheet.html#print**.
4. Registration, Evaluation, Authorisation and Restriction of Chemicals.
5. From EPA media release, "EPA announces new framework to prevent unsafe new PFAS from entering the market," June 29, 2023. Available at: **www.epa.gov/newsreleases/epa-announces-new-framework-prevent-unsafe-new-pfas-entering-market**.
6. From "PFAS strategic roadmap: EPA's commitments to action 2021-2024." Available at **www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf**.
7. From "EU REACH: How to prepare for the proposed PFAS restriction." Available at **bit.ly/3pFFXg9**.
8. EPA PFAS resource repository available at **www.epa.gov/pfas/pfas-resources-data-and-tools**.
9. The ChemSec PFAS Guide is available at **https://pfas.chemsec.org/**.
10. Information on the PFAS Movement is available at **http://chemsec.org/pfas**.

FEATURE

Surface engineering of rolling contact elements

Experts share concurrent findings on the influence of surface properties, recent developments and future directions.

By Dr. Yulia Sosa
Contributing Editor

KEY CONCEPTS

Rolling contact fatigue (RCF) failures are often detected on the surfaces of bearings, gears, etc.

Researchers experiment with different materials and study RCF under different operation conditions to reduce RCF impact.

Surface treatment can affect one or more connected properties in different ways.

Rolling contact elements, especially gears and bearings, experience a wide variety of failure modes including micropitting, spalling, white etching cracks (WECs), cracking, etc. A wide variety of research has been conducted by different research groups globally to enhance their rolling contact fatigue (RCF) life. This includes observing the effect of different case hardening techniques including carburizing and nitriding, revealing effect of crucial phases such as retained austenite (RA), developing novel coatings such as diamond-like carbon (DLC) and carbon black and understanding fundamental crack initiation and propagation under various contact conditions. Recent research studies also focus on specific applications such as agricultural sectors, wind energy, space applications, etc.

This article focuses on capturing a holistic viewpoint on these recent developments and future perspectives with key discussions majorly focused on concurrent findings on surface properties and characteristics of materials that experience rolling contacts such as gears, bearings, cams, etc. Specifically in this article, experts share how they became interested in RCF, and new directions that different research groups are focused on to enhance knowledge on the matter. In addition, experts share different aspects such as heat treatment to modify specific phase and/or microstructure of the surface, novel coatings, post-processing treatments such as shock-peening, impact treatments, etc., to further change surface properties.

Experts' current research activities

STLE member Dr. Sougata Roy, assistant professor, department of mechanical engineering, Iowa State University, has been working in the RCF field for the last 10 years. Roy comments about his research activities: "Initially I started working on understanding the role of RA in major RCF failure modes—in particular micropitting, macropitting or spalling and WEC formation in carburized steel for gear application. RA is a crucial phase in steel, and I worked on varying RA percentages

in AISI 8620 steel by modifying the carburizing heat treatment schemes in different batches while sample preparation."

In another project, Roy focused on running-in phenomena and explored the evolution of hardness and tribofilm growth during running-in process of carburized steel under boundary lubrication regime. "Significant changes on surface roughness characteristics can be observed during micropitting since micropitting is a surface driven failure mode," he says. Roy published an article presenting the correlation between evolution surface roughness and progression of micropitting during RCF.[1] While these research activities were focused on surface roughness and materials-dependent RCF behavior, later Roy explored lubrication behavior during the RCF process. He presented the major potential of phosphonium-based ionic liquids as antiwear and antipitting additives for low-viscosity rear axle lubricants. "We were able to show enhanced protection against surface cracking and micropitting using an ionic liquid additized lubricant having viscosity level half of conventional gear oil. In another lubrication-based effort, I studied the potential of copper(II) oxide (CuO) and tungsten carbide (WC) nanoparticles-based nanofluids on their micropitting life enhancement in carburized steels," Roy shares.

STLE member Dr. Amir Kadiric, a reader in mechanical engineering, department of mechanical engineering, Imperial College London, also briefly describes his research activities in the RCF field. He says that the Tribology Group at Imperial has a long history in RCF research. Some of the past highlights include the 1980s work on the impact of debris on rolling bearing fatigue, which formed the basis for the now well-known contamination factor in ISO bearing life theory, and the 1990s work on the development of test rigs for pitting and micropitting studies, which eventually culminated in the widely used triple-disc micropitting rig (MPR). Kadiric shares: "My recent research in the field focuses on the surface-initiated RCF, which is the dominant mode in modern machines since they often operate under low specific film thicknesses (low lambda ratios). The major aspect of this work is that, rather than looking only at the final failure, it attempts to better understand the actual growth of RCF cracks, from very early stages when they are only tens of microns long, to when they eventually form the final pit. This is a necessary step in improving our predictions of RCF lives of machine elements such as bearings and gears, particularly the predictions of the 'remaining useful life,' i.e., life after an initial RCF crack is formed and detected, which are not possible with current, largely empirical, approaches." Kadiric adds that other aspects of his recent RCF research include the effect of lubricant formulation and surface treatments, such as black oxide and steel composition on RCF damage.

A wide variety of research has been conducted by different research groups globally to enhance their rolling contact fatigue (RCF) life.

STLE member Dr. Jeremy Wagner, technical lead, drivetrain tribology and system simulation, John Deere Product Engineering Center, says that his research has primarily focused on understanding run-in and RCF life at very low lambda conditions ($\lambda < 0.5$),[2,3,4] which is important for applications that have low speed and high load, like off-highway vehicles. One focus area of this work has been on identifying a failure mode transition and the contributing factors. Additional focus areas have included correlating bearing RCF life in the field to calculated life, S-N curve development, the effect of additives and tribofilms, simulation and life models and RCF test acceleration.

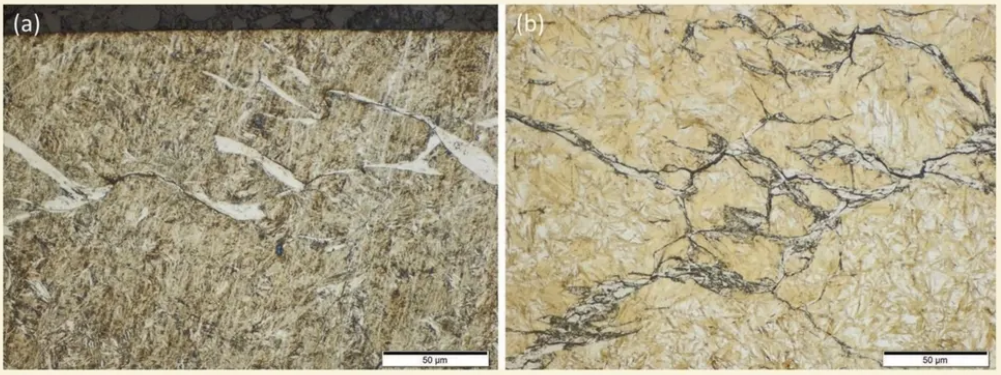


Figure 1. **Effect of retained austenite on white etching crack (WEC) morphology. (a) Low RA and (b) high RA samples failed in spalling mode after WEC formation in the sub-surface region.[10]**

Discussion on key findings on RCF

Roy says that his interest to study deep into RCF started within the topic of RA, which is a crucial phase of steel that has a significant impact on its wear and fatigue life. He shares that in the first phase of his doctoral study at Iowa State University, he elucidated the impact of different heat treatment routes on controlling the RA and micro-tribological behavior of carburized steel.[5] He demonstrated that by combined effect of increased RA and surface hardness, the wear resistance of carburized steel can be improved by up to 40%. Roy also presented the laser surface treatment as an alternate route to heat treat the steel components used in drivetrains. He further shares that he studied the effect of the two most critical laser treatment parameters (laser scanning velocity and shielding gas) to control RA on the sample surface.[6] Roy says that he and his team succeeded in improving the surface hardness of laser treated steel by a maximum of 45%, using the proper selection of scanning velocity and shielding gas. During the next phase of his doctoral study, Roy concentrated on the three crucial RCF failure modes observed in gears and wind turbine bearings, namely micropitting,[7,8] spalling[9] and WEC formation.[10] Roy says that he developed novel protocols to track surface evolution during micropitting initiation and propagation using white light interferometry. He also captured martensitic phase transformation using a micro-X-Ray diffraction technique to address martensitic phase transformation during running-in and later periods of RCF life for drivetrain components. Roy observed that the micropitting life of samples can be improved up to 12 times by increasing RA on the surface. In case of macropitting or spalling, RA content as well as subsurface cracks played crucial roles in failure of components. "Industrial scale drivetrain bearings, particularly those used in wind turbines, often exhibit WEC-induced premature macropitting or spalling well before reaching their RCF design life," Roy says. He adds: "A general common root cause of WEC networks in field bearings is still unknown. However, the microstructural alterations that appear in conjunction with the cracks must form due to local excess in energy causing recrystallization or atomic diffusion. An investigation in collaboration with Argonne National Laboratory provided valuable insights on the impact of RA on WEC morphologies of failed specimens—WEC networks that formed in the samples with higher levels of RA contained a larger number of crack branches, and the white etching area (WEA) adjacent to the crack faces was less developed *(see Figure 1 on page 61)*."

to early crack initiation and rapid crack propagation. The 15% and 70% RA samples showed initiation and propagation of micropitting. Significant propagation of micropitting was accompanied by changes in surface roughness parameters, specifically by a decreasing trend of skewness and increasing trend of kurtosis," Roy adds.

Roy says that in the lubrication-focused efforts in RCF, the nanofluids consisting of 1% nanoparticles by weight and 1% by

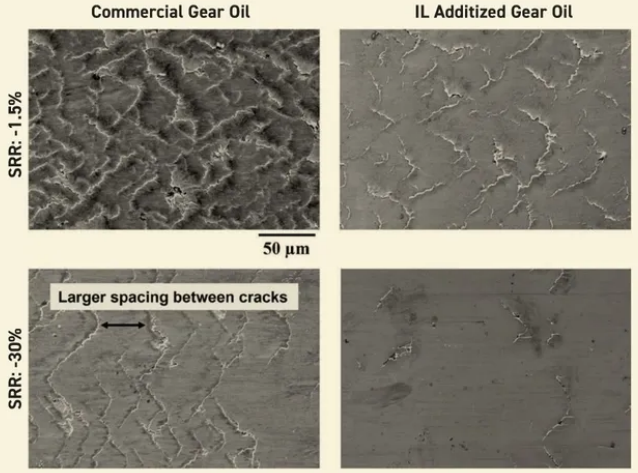
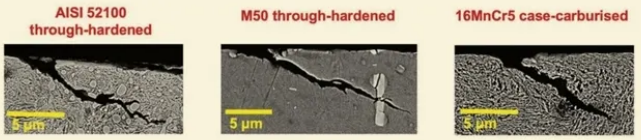


Figure 2. **Surface topography of roller samples under commercial (left) and IL-based (right) lubricant cases.[13]**

In the running-in focused investigation,[11] Roy and his team presented how the surface hardness of 16MnCr5 steel gets evolved during the running-in period, which is very important in the RCF process and can impact RCF life significantly. The results showed that a higher initial composite roughness led to greater gains in hardness as compared to higher contact pressure during the running-in process. "In another effort,[1] the evolution of amplitude and spatial parameters were investigated during RCF experiments on carburized samples with around 0%, 15% and 70% RA under boundary lubrication condition," shares Roy. "The 0% RA samples failed due

weight of oleic acid surfactant in polyalphaolefin (PAO) showed enhanced micropitting life as compared to standalone PAO.[12] These showed the great potential of select nanoparticles on impacting RCF life. "Stringent government regulation in exhaust emission and increased demand for fuel economy are the prime contributors for deeper research in finding high-performance low-viscosity lubricants," Roy explains. "Since the invention of lubrication applications of ionic liquids (ILs), it has been extensively studied for use in various engineering sectors, including high vacuums and high temperatures." While working at Oak Ridge National Laboratory, ▶



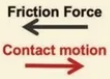


Figure 3. **SEM images showing typical morphology of early surface-initiated RCF cracks in different bearing and gear steels. Cracks generated in a triple-disc contact fatigue rig. (p_0 = 3 GPa, SRR = -5%) mixed lubrication regime. Sections in rolling direction after polishing and etching. In all images, friction acts to the left and contact moves to the right.** *Figure courtesy of A. Kadiric and P Rycerz, Imperial College London.*

he studied phosphonium phosphate[13] and phosphonium phosphinate[14] ILs for rear axle lubrication. Roy shares: "Test conditions were established to simulate contact conditions near pitch line and dedendum of gears when a vehicle is driven during cold start, highway towing and overload conditions. Although the viscosity of IL-based lubricants was around half of commercial SAE 75W-90 gear oil, it still demonstrated significantly improved surface protection in terms of surface crack reduction and wear reduction *(see Figure 2 on page 62)*." Roy adds: "Chemical interaction of ILs with sample surface and wear protection mechanisms were studied in detail by conducting scanning transmission electron microscopy (STEM) imaging of the focused ion beam (FIB) cross-sectioned tribofilms and non-contact optical profilometry-based techniques."

A lot of different directions-based RCF investigations are being carried out by various groups across the globe.

Kadiric also shares about how his interest to study deep into the particular areas on RCF developed and some of his key findings: "This research is multifaceted, but its overall aims are straightforward: to help extend the contact fatigue lives of machine elements and to improve our ability to predict these lifetimes, both of which can reduce maintenance and downtime costs and improve safety of many mechanical systems. By detecting very early RCF surface cracks, tens of microns in length, and monitoring their growth, we have been able to show[15] that crack propagation, rather than initiation, can consume the majority of the total RCF life." Furthermore, Kadiric adds: "We have shown that for later phases of surface crack growth, it is possible to predict their propagation rates using linear elastic fracture mechanics approaches that are widely used in structural fatigue, including Paris' law type equations.[16] This suggests that despite its many complexities, the fundamental mechanisms of RCF crack growth are the same as those for structural fatigue cracks." The significance of this is far from purely academic—in practice it opens up the possibility of using well-established tools, widely used in classical fatigue engineering practice for prediction of fatigue lifetimes in structures, to improve our predictions of RCF lives in components such as bearings and gears. This is particularly relevant to predictions of remaining useful life I mentioned earlier," he says. Other interesting findings are that steel composition has a significant influence on RCF crack propagation rates, with surface RCF cracks seemingly growing slower in M50 steel, for example, than in standard AISI 52100 through-hardened bearing steel or a typical case-carburized gear steel, Kadiric shares. He says: "The crack morphology also differs for different steels, and the 3D crack shape evolves over time, so that the common assumption of a half-penny shaped surface RCF crack is not always valid." Figure 3 shows examples of typical early surface RCF cracks.

Kadiric continues: "In regard to surface treatments, our recent RCF research has consistently shown that one of the primary ways in which such treatments can improve surface fatigue performance is by optimizing the running-in process, so that the magnitude of the asperity stresses, which are ultimately responsible for surface fatigue, is reduced.[17] The exact mechanism by which this is achieved varies between treatments, with for example black oxide promoting running-in of the surface on which it is applied,[18] whereas hard coatings, such as DLC, promote running-in on the opposing surface." To achieve the desired effect of balancing wear and fatigue performance, care should therefore be taken to apply a given treatment to the correct surface in a tribopair, Kadiric says. "Interestingly, along with the reduction of friction, the optimization of this running-in process also is a primary way in which a lubricant formulation can improve contact fatigue performance—the aim in both cases is to get the right balance between wear and fatigue, which will maximize the component life," he adds.

Wagner says that his interest to study deep in RCF was sparked by two things: "1.) My work on drivetrains for off-road vehicles for 25 years and 2.) the published literature on life adjustment factors for lambda ratio didn't study deeply the case when $\lambda < 0.5$." Wagner shares that in his work, it was discovered that for the oil tested,[3] there was a lambda ratio at which the failure mode changed from micropitting to pitting *(see Figure 4)*, and this failure mode transition was affected by the additive elements present in the tribofilm.

Future research directions

While describing future directions for major research in surface engineering of rolling contact elements, Roy says that currently, a lot of different directions-based RCF investigations are being carried out by various groups across the globe. Some of them are fundamental studies such as understanding various RCF failure modes via analytical, computational and experimental efforts. Some studies are applied that focus on exploring novel coatings and/or surface engineering routes to enhance the RCF life of components. "A lot of efforts from lubrication aspects by introducing novel nanoparticles and ILs also are being carried out," Roy states.

Adding to the above, Kadiric also shares his thoughts on some major research directions in surface engineering of rolling contact elements: "I think much of the new developments in this respect will be driven by the need to reduce the environmental impact of the relevant applications, and

there are many ways to achieve this. If we are talking about making a step change in extending RCF lifetimes, then I think the best way to achieve this is through development of new materials that are better able to deal with surface-initiated damage in particular." He explains: "Notwithstanding incremental changes, typical steels used for rolling bearings and gears are over 100 years old. Modern machines operate under thinner lubricant films and higher power densities, causing more asperity interactions and, hence, failures at the surface itself. In some novel applications, machine elements are subjected to harsh environments—for example, hydrogen."

Kadiric adds that surface coatings can help in some situations, but too often they have limited lifetimes themselves. Ceramics are an excellent solution in selected cases but are often not cost effective. "Development of such new materials should make use of the accumulating knowledge on how surface RCF cracks initiate and grow, as discussed earlier," he says. "A good example is the use of surface treatments that optimize the running-in process to subsequently reduce asperity stresses and, hence, surface fatigue. Another example is the recent attempts to develop new steels, which are better able to trap hydrogen to prevent it from adversely affecting fatigue lifetimes. The environmental impact of making and using such materials must not be forgotten, and the growing interest in 'green steels' is very welcome in this respect," Kadiric states.

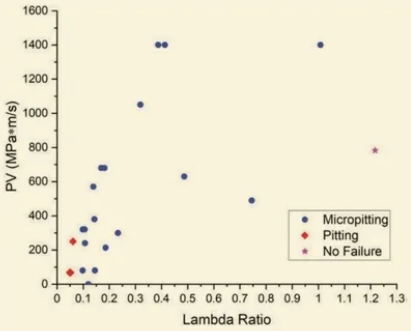


Figure 4. **Test failure modes, lambda ratio versus Hertzian pressure and sliding velocity (PV).**[2]

He continues: "Of course, simply reducing the downtime of machines or avoiding unnecessary component replacement can have an enormous positive environmental impact itself. I think the work on improving the models for RCF lifetime predictions, specifically focusing on surface initiation, crack propagation and remaining useful life, will form an important part of our ongoing

efforts. These models are likely to be more deterministic than the current ones, but we must not forget that RCF failures are inherently a statistical phenomenon, and this is where I think some of the new machine learning methods may find a good use. An effective combination of machine learning applied to data from appropriate condition monitoring sensors and our evolving understanding of RCF physics has a potential to revolutionize our predictions of RCF lifetimes in practical applications."

Rolling contact elements are one of the most crucial components in machinery.

Wagner contributes to the topic of the future research directions with several ideas: "I think three things come to mind when we talk about surface engineering: 1.) surface texture, 2.) coatings and 3.) residual stress enhancement, typically by means of peening. Of these three items, I think residual stress enhancement is the area where more work would be beneficial, particularly the effect of different manufacturing processes on the residual stress magnitude." He continues: "I also think there are three other areas that could benefit from additional research. The first is the effect of the near surface microstructure, specifically the first few microns, on the RCF performance." Wagner explains that it is affected by the manufacturing process, and it has shown to be a factor in engine cylinder performance. "The second is how run-in affects RCF performance. It is commonly accepted that run-in improves RCF performance, but to my knowledge this has not been studied deeply or quantified. The third is the effect of the resulting tribofilm on the RCF performance," Wagner shares.

Summary

Rolling contact elements are one of the most crucial components in machinery. Enhancing the operational life and reliability of these components is a long-studied topic of research, both via experiments and digital modeling. Modern machines utilize components which have superior surface finishes and clean lubricants but also operate under thinner lubricant films and higher power densities. Future research needs to account for one of the major challenges, which is that surface treatment can impact one or more connected properties in different ways; for example, as discussed in this article, increasing RA on the surface may help enhance micropitting life. In addition, future research should also focus on novel lubricants which need to be developed alongside metallurgical improvements for the new surfaces. Therefore, it is beneficial for the industry to continue sharing knowledge and progress with the developments of new innovative solutions aligned with sustainability and energy efficiency goals.

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1. Roy, S., White, D. and Sundararajan, S. (2018), "Correlation between evolution of surface roughness parameters and micropitting of carburized steel under boundary lubrication condition," *Surface and Coatings Technology,* **350**, pp. 444-452.
2. Wagner, J. J. and Sundararajan, S. (2022), "Tribofilm characterization and residual stress changes in rolling/sliding contacts under low lambda conditions," *Wear,* **500-501**, 204350, **doi.org/10.1016/j.wear.2022.204350**.
3. Wagner, J. J. and Sundararajan, S. (2021), "Failure mode mapping for rolling/sliding contacts under low lambda conditions," *Wear,* **477**, 203855, **doi.org/10.1016/j.wear.2021.203855**.
4. Wagner, J. J., Jenson, A. D. and Sundararajan, S. (2017), "The effect of contact pressure and surface texture on running-in behavior of case carburized steel under boundary lubrication," *Wear,* **376-377**, pp. 851-857, **doi.org/10.1016/j.wear.2017.02.016**.
5. Roy, S. and Sundararajan, S. (2016), "The effect of heat treatment routes on the retained austenite and Tribomechanical properties of carburized AISI 8620 steel," *Surface and Coatings Technology,* **308**, pp. 226-243.
6. Roy, S., Zhao, J., Shrotriya, P. and Sundararajan, S. (2017), "Effect of laser treatment parameters on surface modification and tribological behavior of AISI 8620 steel," *Tribology International,* **112**, pp. 94-102.
7. Roy, S., Ooi, G. T. and Sundararajan, S. (2018), "Effect of retained austenite on micropitting behavior of carburized AISI 8620 steel under boundary lubrication," *Materialia,* **3,** pp. 192-201.
8. Ooi, G. T., Roy, S. and Sundararajan, S. (2018), "Investigating the effect of retained austenite and residual stress on rolling contact fatigue of carburized steel with XFEM and experimental approaches," *Materials Science and Engineering: A,* **732**, pp. 311-319.
9. Roy, S. and Sundararajan, S. (2019), "Effect of retained austenite on spalling behavior of carburized AISI 8620 steel under boundary lubrication," *International Journal of Fatigue,* **119**, pp. 238-246.
10. Roy, S., Gould, B., Zhou, Y., Demas, N. G., Greco, A. C. and Sundararajan, S. (2019), "Effect of retained austenite on white etching crack behavior of carburized AISI 8620 steel under boundary lubrication," *Tribology Letters,* **67:** 40.
11. Jenson, A. D., Roy, S. and Sundararajan, S. (2018), "The evolution of hardness and tribofilm growth during running-in of case carburized steel under boundary lubrication," *Tribology International,* **118**, pp. 1-10.
12. Roy, S., Jazaa, Y. and Sundararajan, S. (2019), "Investigating the micropitting performance of copper oxide and tungsten carbide nanofluids under boundary lubrication," *Wear,* **428**, pp. 55-63.
13. Roy, S., Speed, L., Viola, M., Luo, H., Leonard, D. and Qu, J. (2021), "Oil miscible phosphonium-phosphate ionic liquid as novel antiwear and antipitting additive for low-viscosity rear axle lubricants," *Wear,* **466**, 203588.
14. Roy, S., Stump, B. C., Luo, H., Leonard, D. and Qu, J. (2021), "Why does a phosphonium-phosphinate ionic liquid protect the contact surfaces from wear and micropitting but increase vibration when used as an additive in rolling-sliding lubrication?" *Tribology International,* **159**, 106949.
15. Rycerz, P., Olver, A. and Kadiric, A. (2017), "Propagation of surface initiated rolling contact fatigue cracks in bearing steel," *International Journal of Fatigue,* **97**, pp. 29-38.
16. Kunzelmann, B., et al. (2023), "Prediction of rolling contact fatigue crack propagation in bearing steels using experimental crack growth data and linear elastic fracture mechanics," *International Journal of Fatigue,* **168**, 107449.
17. Ueda, M., Spikes, H. and Kadiric, A. (2019), "In-situ observations of the effect of the ZDDP tribofilm growth on micropitting," *Tribology International,* **138**, pp. 342-352.
18. Ueda, M., Spikes, H. and Kadiric, A. (2022), "Influence of black oxide coating on micropitting and ZDDP tribofilm formation," *Tribology Transactions,* **65** (2), pp. 242-259.

TOP STORIES

STLE announces executive director succession plan

STLE announces that **Edward P. Salek**, STLE executive director, is retiring effective January 2024. He has been with the society for 27 years. Salek will be succeeded by **Rebecca Lintow**, current STLE director of professional development. Lintow will become STLE executive director effective Oct. 1, and Salek's title will become outgoing executive director.

STLE Immediate Past President Ryan Evans, from The Timken Co. and chair of the search committee, says, "STLE's field of tribology and lubrication engineering is positioned today to make major contributions to our world in meeting the challenges of sustainability and energy efficiency. STLE has never been more important than it is today. Edward P. Salek brought a steady hand, publication expertise and visionary leadership as he worked with volunteers to lead our community for 27 years. STLE is strong today as a result. As Ed transitions his executive director role to Rebecca Lintow starting on Oct. 1, our society is excited to work with Rebecca as she leads the expert STLE staff to achieve our 2023-2026 Strategic Plan objectives. Rebecca brings to the role proven experience in leadership, management, educational and professional development, and an excellent professional network. We are so excited to see her vision put into action over time."

Edward P. Salek

Salek joined STLE in 1996 and has been STLE executive director since May 1997. During his tenure with STLE, Salek has directed development and implementation of an evergreen strategic planning process that has sustained membership and provided new programs and services. He frequently represented the organization and profession at meetings with local affiliates, related associations, corporate members and publishers.

"STLE is a remarkable organization, and I am proud of what has been accomplished during the past 27 years," says Salek. "This transition to our new executive director comes at a time of unique opportunity for the profession. I am certain that Rebecca, working in combination with leadership and staff, will enable STLE to make the most of those opportunities in the years ahead."

Lintow joined STLE's staff in October 2021 as director of professional development. She obtained her bachelor of arts degree from Benedictine University and has more than 15 years of experience with nonprofit organizations and association management. She previously worked for the AED Foundation as director of sales and development and the Mechanical Contractors Association of Chicago as senior director of engagement.

Lintow's primary responsibility as STLE director of professional development was directing members or member committees in the development and execution of continuing technical education. She also was responsible for STLE membership, section relations and certification programs. She obtained the Certified Association Executive (CAE) credential in 2022.

Lintow says, "I am pleased to have been selected to serve as STLE's next executive director and to continue the organization's mission of 'perfecting motion.' I am honored to follow Ed in this role. I look forward to working closely with the STLE staff, leadership and volunteers to continue STLE's 80-year legacy of fulfilling its 'connect, learn, achieve' value proposition."

Rebecca Lintow

STLE President Hong Liang with Texas A&M University comments, "STLE's leadership and membership are a combination of diversified personnel, expertise and markets. Rebecca's appointment further enhances the strength of STLE. The STLE Board of Directors is looking forward to a smooth transition into a new era."

ASTM International honors Gareth Fish and Ted McClure

STLE Fellow **Gareth Fish** and STLE member **Ted McClure** have received the 2023 Frank C. Brautigam award from **ASTM International** for their contributions to the wear and erosion committee (G02).

This award is given in memory of Frank C. Brautigam, who served as task group chair on abrasive wear from 1980-1986, to recognize outstanding and effective work in the development of new ASTM International standards.

Gareth Fish

Dr. Fish has been recognized for his significant lifetime contributions to education and academic literature surrounding lubrication greases, as well as his decades of innovation within the industry.

An ASTM International member since 2009, Dr. Fish has been previously honored by the committee with two Awards of Appreciation in 2018 and 2021. The first was for his contributions to grease testing, and the second was for contributions to lubricants for marine applications.

Fish is currently a technical fellow at The Lubrizol Corp.—a Berkshire Hathaway company that leverages its unmatched science and innovation to solve complex challenges for customers, drive sustainable and measurable results and help millions of people, communities and businesses around the world move cleaner, create smarter and live better every day—a position he has held since 2010, and his primary 35-year career focus has been on lubricating greases. He is a member and/or certified specialist with a variety

of other organizations, including the Royal Society of Chemistry, STLE, NLGI and more.

McClure has been recognized for his extensive career in industrial chemical product development with a focus on lubricants, over which he has specialized in laboratory operations, training and more.

McClure has been a member of ASTM International since 2016 and holds professional memberships in STLE, the North American Deep Drawing Research Group (NADDRG) and the American Chemical Society (ACS). He holds the STLE Certified Metalworking Fluids Specialist™ (CMFS) certification, is past chair of the STLE Chicago Section and is past chair of the STLE CMFS Certification Steering Committee.

Ted McClure

McClure is currently the director of technical resources at Sea-Land Chemical Corp., a position he has held since 2014 after his tenure as president of TribSys LLC. In 1974 he received his bachelor of science degree in chemistry from Miami University.

Palmer Holland distribution expansion with LANXESS

Cleveland, Ohio-based **Palmer Holland**, a North American specialty chemical and fine ingredient distributor, announces a distribution expansion with **LANXESS'** polymer additives business.

A current distributor for LANXESS in the northern U.S., Palmer Holland will now be the nationwide distributor in the U.S. for the K-FLEX® line of plasticizers.

K-FLEX® dibenzoate esters are non-phthalate plasticizers, modifiers and coalescents. They are compatible with a wide range of polymers and are commonly used in adhesives, sealants, coatings, paints, flooring, wall coverings, synthetic leather and personal care.

K-FLEX® plasticizers optimize the manufacturing processes and the properties of end-products. They are highly compatible with polar polymers in water-based adhesive systems, and they improve the film formation of paints and coatings. In PVC production, the fast-gelling dibenzoates can speed up processes, helping formulators achieve greater efficiency.

The LANXESS polymer additives business offers high quality additives and finishing chemicals to improve the processability of ingredients and the properties of end-products.

MOGoil purchased by Process Oils

Process Oils, Inc., an Ergon company headquartered in Houston, Texas, announces the purchase of **MOGoil GmbH**. Since 2006, MOGoil has served its customer base in Europe and beyond by supplying them with optimal base oil solutions from a global network of long-term supply partners. Now a wholly owned subsidiary of Process

Oils, MOGoil is positioned for a more sustainable future as a leader in international base oil distribution.

"The addition of MOGoil will expand our regional expertise and further position us to better meet global market needs on a larger scale," says Lance Puckett, president of Process Oils. "We are excited to have MOGoil join the Ergon family as both companies have a passion for exceeding customer expectations and striving to be the world's preferred solutions provider.

In a joint statement, managing directors for MOGoil say: "Being a part of the Ergon family of companies means major growth opportunities for MOGoil, and we are pleased to join a company known for extending remarkable support to employees, customers and partners."

HF Sinclair and Holly Energy Partners agreement

HF Sinclair Corp. and **Holly Energy Partners, L.P.** (HEP) announce that they have entered into a definitive merger agreement for HF Sinclair to acquire all of the outstanding common units of HEP not owned by HF Sinclair or its affiliates in exchange for a combination of common stock, par value $0.01 per share, of HF Sinclair and cash.

HF Sinclair's CEO and president, Tim Go, comments, "We are pleased to announce this strategic transaction which we believe simplifies our corporate structure, reduces costs and further supports the integration and optimization of our portfolio. We expect the transaction to be accretive to earnings per share and available free cash flow within the first 12 months, further supporting our capital allocation strategy of returning excess cash to shareholders."

Univar Solutions and Climax Molybdenum agreement

Univar Solutions Inc., a leading global solutions provider to users of specialty ingredients and chemicals based in Downers Grove, Ill., and **Climax Molybdenum Co.**, the world's largest producer of molybdenum and molybdenum-based chemicals, announce a geo-expansion of the companies' existing partnership for molybdenum products, including Molysulfide® used in greases and coatings applications.

"As a leading global distributor of specialty chemicals, we recognize the growing worldwide demand for high quality molybdenum products. Building upon our existing relationship and collaboration with Climax, expanding into new regions is a high priority as it expands our product offering and allows us to provide Climax's noncontract lubricants customers in the U.S. and Latin America reliable access to these key elements and chemistries," says Federico Montaner, global vice president of lubricants and metalworking fluids for Univar Solutions. "We look forward to continuing to work together to meet and exceed the highest standards for quality and dependable supply sourcing, which our valued customers have come to expect and deserve."

Michael Kendrick, president, Climax Molybdenum Co., says, "As the only fully integrated domestic (U.S.) producer of molybdenum, Climax's global operations and local customer care provide our worldwide partners with the most reliable supply and highest quality molybdenum products. We have developed a Responsible Care® Policy as part of our commitment to the Principles of Responsible Care® and to product and process safety, environmental stewardship, health and security at our global operations. We're excited to expand our relationship with Univar Solutions, a company likewise committed to helping our mutual customers develop and bring forward more sustainable solutions now and into the future."

Ingevity announces renewable energy project

Ingevity Corp. announces it has entered into a renewable product purchase agreement (RPPA) with a subsidiary of **NextEra Energy Resources, LLC**, to produce offsetting renewable energy to lower Scope 2 emissions related to Ingevity's U.S. manufacturing locations.

Ingevity aims to reduce the company's greenhouse gas (GHG) emissions and be carbon neutral for absolute GHG emissions from manufacturing operations by 2050. Ingevity's sustainability commitment includes decarbonization through increasing the use of renewable energy in its operations and by collaborating with renewable energy producers like NextEra Energy Resources to increase the amount of renewable energy available in the U.S.

"Ingevity was founded on using renewably sourced chemistries and materials to purify, protect and enhance," says Ingevity president and CEO John Fortson. "Collaborating with NextEra Energy Resources for the development of a solar facility in a location in the U.S. with high electricity demands to create renewably sourced energy is a natural extension of our sustainability profile and an important element in our effort to achieve carbon neutrality for the benefit of our operations and the industries that rely on our products to advance their own sustainability goals."

As part of the agreement, Ingevity will receive 85 megawatts of capacity at a new NextEra Energy Resources solar site to be constructed in North Texas. With Ingevity's commitment to the project and NextEra Energy Resources' deep expertise in developing and generating renewable energy, the project will contribute a significant source of sustainable energy to Texas.

"We have a history of collaborating with Ingevity to develop customized solutions to help meet their goals," says Rebecca Kujawa, NextEra Energy Resources president and CEO. "In terms of reducing carbon emissions, a solar project of this scale is equivalent to the electricity needed to power an average of 14,000 homes per year, with the added benefits of generating new jobs and creating economic impacts for Texas and beyond."

NextEra Energy Resources and Ingevity expect the solar facility to be fully operational by the end of 2025.

TotalEnergies, Baker Hughes and others invest in Zhero Europe

TotalEnergies, Baker Hughes, Technip Energies, Azimut (through the fund Azimut ELTIF – Infrastructure & Real Assets ESG) and other investors have signed a preliminary agreement to invest in **Zhero Europe** in order to develop large scale renewable energies projects in Europe and Africa spanning across renewable power generation, power interconnections and green molecules.

Zhero Europe was founded with the vision that large integrated projects, including generation from high quality wind and solar resources, and captive long-distance exports, would be the most effective way to accelerate the energy transition in high demand areas.

Paddy Padmanathan and Alessandra Pasini, respectively chair and CEO of Zhero Europe, comment: "We are thrilled to welcome new investors who share our ambition to accelerate the energy transition by delivering large scale bankable projects that will inspire others to follow. Green energy is already cheaper than fossil fuels in many countries, and we need to accelerate project development and construction to mitigate the growing gap between climate action and climate ambition. There is no time to lose."

Stephane Michel, president gas, renewables and power at TotalEnergies, says: "Zhero Europe's bold ambition is to bring abundant, affordable and clean energy from the best producing location to the large consuming markets and notably from North Africa to Europe. We welcome the opportunity to join forces with Zhero Europe and its other investors to support the development of those pioneering projects for the mutual benefit of Europe and Africa."

Chevron Oronite celebrates 25 years in China

San Ramon, Calif.-based **Chevron Oronite** celebrates 25 years in China with an event to celebrate the successful operation of its manufacturing facility in Ningbo, China. Recognizing the importance of the China market, Chevron Oronite first established its presence with a sales office in Beijing back in 1998. Twenty-five years later, the company's footprint in China has expanded with another sales office and technology support center in Shanghai, and the new manufacturing plant in Ningbo, Zhejiang province.

Chevron Oronite first announced its intention to build a manufacturing plant in China in 2015 and selected Ningbo as the preferred location in mid-2018. The location is part of the Ningbo Economic & Technical Development Zone (NETD), which is located near the Ningbo Port, one of the largest ports in the world in terms of annual cargo throughput. Construction commenced in late 2018, and the plant was fully commissioned in 2020. Commercial production started in 2021, helping ensure reliable supply of components and additives to China customers.

"China is an important strategic market for us in Chevron Oronite, and the completion of our Ningbo plant signifies our commitment to grow in China and the broader Asia region," says Mitra Kashanchi, president, Chevron Chemicals. "True to Chevron Oronite's strong belief in providing exceptional reliability, our Ningbo plant increases the capabilities of our global supply chain and puts Oronite closer to our local China customers. We are now able to provide greater flexibility and security of supply across China, Asia and beyond."

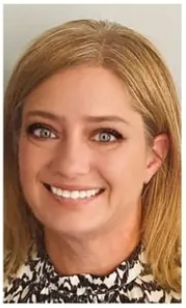
Keng Yang Lim, general manager, manufacturing and supply chain, Asia Pacific Region, Chevron Oronite, says, "The celebration of our 25th anniversary in China as well as the successful operation of the Ningbo plant is an important milestone for our team who worked through this project since its ideation in 2015. I am very proud of the team for their relentless determination for pulling through the multiple challenges during the construction, commissioning and first supply stages."

From left to right: Eugene Ng, Chevron Oronite; Cary Knuth, Chevron Oronite; Brett Cooley, Chevron Oronite; Keng Yang Lim, Chevron Oronite; Mitra Kashanchi, Chevron Chemicals; Deputy District Mayor Ms. Cheng Zhan, Beilun District Government, Ningbo & Deputy Director of the Management Committee of Ningbo Economic and Technological Development Zone; Bai Qiang Yu, Chevron Oronite; and Kevin Lin, Chevron Oronite. *Photo courtesy of Chevron Oronite.*

PROMOTIONS & TRANSITIONS

Julie O'Rourke named STLE membership manager

Julie O'Rourke joined **STLE's** staff in September as membership manager and will work from the society's international headquarters office in Park Ridge, Ill.



Julie O'Rourke

O'Rourke obtained her bachelor of arts degree in journalism from Eastern Illinois University. She was previously membership marketing manager for the Illinois CPA Society, director of membership for the International Association of Defense Council, assistant director of membership for the Association Forum of Chicagoland and director of membership for the Coin Laundry Association.

O'Rourke's primary responsibilities include developing and implementing strategies designed to increase membership recruitment and retention and serving as the liaison for STLE Local Sections. You can reach her at ***jorourke@stle.org***, 224-985-0016.

Valvoline announces CEO transition

Valvoline Inc., a trusted leader in preventive automotive maintenance delivering quick and convenient service, announces that **Sam Mitchell** is retiring as CEO and a member of the board of directors. Mitchell will be succeeded by **Lori Flees**, current president of retail services, as the company's CEO. Flees also will join the company's board.

Sam Mitchell

"Leading this company has been the highlight of my career. I will always be grateful for the experience of working with the talented and dedicated people at Valvoline, and I wish them all future success," says Mitchell. "I have had the privilege of working side by side with Lori for the past year. Throughout her career and in our time working together, she has proven to be a strategic thinker with a natural ability to unite teams and drive results. The board and I have great confidence that she is the right leader for Valvoline as the company focuses on its future as a high-growth, high-margin, pure-play retail services business."

Flees has served as president of Valvoline retail services for the past year. In this role, she has led the company's operations, driving

top and bottom-line growth to new record levels. She will continue in her role as president, in addition to serving as the company's CEO.

"It is an honor and a privilege to be named the next CEO of Valvoline," says Flees. "Together with our talented team and strong franchise partners, we will continue to deliver a quick, easy and trusted customer experience, while investing strategically to drive best-in-class value creation for our shareholders. I want to thank the board for their trust in me. I also would like to express my appreciation to Sam Mitchell for his mentorship and successful leadership of Valvoline through a critical time of change and growth."

Lori Flees

Azelis CEO changes

Azelis Group NV, a leading global innovation service provider in the specialty chemicals and food ingredients industry, announces that its board of directors has appointed **Anna Bertona** as new CEO, starting on Jan. 1, 2024. She will succeed Dr. Hans Joachim Müller, who has decided to retire at the end of the year. Bertona has been nominated to join the Azelis board of directors.

Bertona brings a wealth of industry experience and intimate knowledge of Azelis to the role of group CEO, having worked at Azelis for almost a decade, most recently as CEO and president Europe, Middle East and Africa (EMEA) since 2016. In her role as CEO and president EMEA, she strengthened relationships with principals, invested in innovation capabilities, and grew the EMEA business through a combination of organic growth and acquisitions. Bertona also was instrumental in helping shape the strategy of the group, having started as head of strategy in 2013. In addition, as the executive committee sponsor for the group's sustainability agenda, Bertona has consistently demonstrated her commitment to the group's objective to lead the industry in sustainable value propositions.

Anna Bertona

Also, Azelis announces that **Todd Cottrell** will assume the role of CEO of Azelis Americas when Frank Bergonzi retires. To ensure a seamless transition, Bergonzi will support Cottrell with onboarding into his new role, and subsequently will remain available as a consultant to contribute to Azelis' growth strategy in the Americas through the end of 2025.

Cottrell brings more than 30 years of expertise and industry knowledge that span both technical and executive roles. He has worked for some of the global leaders in the coatings, adhesives, sealants and elastomers (CASE) industry, his last position having been managing director Americas for a large European manufacturer. Over his extensive career, Cottrell also served in regional director and regional president roles in France and China, as well as multiple industry board positions. Cottrell holds a bachelor of science degree in chemical engineering from Michigan Technological University and a master of business administration degree from Duke University, both in the U.S.

Todd Cottrell

Want to be recognized in TLT?
If you have news about a new employee or if someone in your company has been recognized with an award or any other interesting items, let us know. Please send us your news releases and photos for publication in Newsmakers to TLT Magazine, Attn: Rachel Fowler, 840 Busse Highway, Park Ridge, IL 60068, ***rfowler@stle.org***.

Photo courtesy of Master Fluid Solutions.

Semisynthetic metalworking fluid

Master Fluid Solutions announces its new, semisynthetic microemulsion coolant with a formula that offers the performance of a heavy-duty soluble oil with the cleanliness of a semisynthetic. **TRIM® MicroSol® 685XT** provides superior corrosion inhibition on all ferrous and nonferrous metals, performing well where traditional soluble oils may not cool sufficiently. TRIM MicroSol 685XT is an excellent alternative to soluble oils on high-silica aluminum alloys and is compatible with a wide range of materials. With extreme hard water stability, TRIM MicroSol 685XT maintains superior sump life without the use of tank side additives and is free of nitrites, phenols, sulfurized extreme pressure additives and triazine.

Master Fluid Solutions
Perrysburg, Ohio
(800) 874-0105
www.masterfluids.com

Electric vehicle fluid solutions

Petro-Canada Lubricants, an HF Sinclair brand, launches a new line of purpose-built lubricant solutions for electric vehicles (EVs)—**Petro-Canada Lubricants EVR**. The launch of EVR lubricants enables Petro-Canada Lubricants to support OEMs to design optimal solutions to current EV challenges and drive innovation in the design of future high-performance EV technology. To help enable enhanced performance, protection and reliability for EVs, Petro-Canada Lubricants introduces the following new product brands: EVR Driveline, EVR Thermal Management and EVR Motor Greases. EVR fluids and greases provide OEMs with improved material compatibility, efficient power transfer and improved equipment performance to enable the development of advanced driveline, axle and battery technologies for use across a range of sectors, including automotive, heavy- and medium-duty transportation.

Petro-Canada Lubricants, an HF Sinclair brand
Mississauga, Ontario, Canada
(866) 335-3369
https://lubricants.petro-canada.com

Photo courtesy of Petro-Canada Lubricants.

Photo courtesy of Cannon Instrument Co.

Digital vacuum regulator

Cannon Instrument Co. announces its new digital vacuum regulator: **DVR-3000**. This new design, with digital display, is easy to use and reaches set point faster than previous models. The DVR-3000 comes factory set to provide precise measurement and control of vacuum at 300 mm Hg below atmospheric pressure (consistent with requirements in ASTM D2171). With an operating range of 95-450 mm Hg below atmospheric pressure, customers can effortlessly adjust the vacuum set point to anywhere within this operational range using the convenient rotary control and digital display. With its compact size, the small footprint optimizes valuable benchtop space. Each unit is supplied with a National Institute for Standards and Technology (NIST) certification of measurement accuracy. The solid-state components are mercury free. The vacuum set point may be altered to fit customer-specific application needs, and the trusted Cannon® platform offers reliability and dependable support.

Cannon Instrument Co.
State College, Pa.
(800) 676-6232
www.cannoninstrument.com

Polymer for cleansing formulations

Lubrizol Life Science Beauty (LLS Beauty) is making thickening and stabilizing challenging-to-thicken cleansers easier with its new **Carbopol® SC-800 polymer.** The rheology modifier solution for mild and sulfate-free formulations is ideal for shower gels, shampoos and facial cleansers. Carbopol® SC-800 polymer has the best thickening efficiency, clarity and suspension properties in studies comparing it to other hydrophobically-modified polymers. This allows formulators the versatility to create unique aesthetics in their skin cleansing formulations, including suspending natural beads, scrubs and other cleansing elements with ease and confidence. Foam generation studies also showed that the polymer doesn't negatively impact foam quality, both in the foam volume generated and its foam morphology. As a result, formulations have the lather quality consumers look for in rinse-off beauty solutions. Carbopol® SC-800 polymer is the latest solution in Lubrizol's Carbopol® family of polymers, well known for their versatility and used extensively in beauty and home care products.

The Lubrizol Corp.
Wickliffe, Ohio
(440) 943-4200
www.lubrizol.com

Want to be recognized in TLT?

If you have a new company product to share, let us know. Please send us your information and photos for publication in New Products to TLT Magazine, Attn: Rachel Fowler, 840 Busse Highway, Park Ridge, IL 60068, ***rfowler@stle.org***.

SOUNDING BOARD

Bearings and bearing lubrication

Executive Summary
TLT readers work in many diverse settings and, as a result, use many different types of bearings. Some stick with well-known types such as roller bearings or journal bearings, while others are using newer designs like ceramic bearings. New developments in coatings and solid lubricants have increased the efficiency of classic bearing types. Test methods also vary, with some readers reporting that they use proprietary testing, others utilizing third-party testing services and a majority listing popular methods such as FE8 and four-ball test.

Q.1 What kind of bearings do you work with lately that have new designs or improved performance?

Ceramic, graphite filled, poly filled and linear rail.

Hybrid ceramic bearings.

High speed ball bearings, low friction tapered roller bearings and high performance wind turbine main bearings.

Ball bearing, the usual ones.

Design auto lube system for crusher, mobile equipment in mining and construction.

Fully ceramic bearings.

Rolling contact bearing.

Refined thrust bearing spring bed designs and fluid pivot journal bearing for misalignment accommodation.

Solid dry film lubricant and journal bearings.

No new designs—most of the bearings that I have worked with lately were regular roller bearings, similar to wheel bearing. They are grease lubricated. I use a calcium sulfate grease with an ISO viscosity of 220.

Oil bearing, gas bearing and magnetic bearing.

Journal—old design, reliable performance.

Plain bearings with reciprocating rotary motion that had solid lubricating coatings on the tribo-polymer-forming basis, fabric made coatings, polytetrafluoroethylene (PTFE) + bronze compounds and self-lubricating materials. The best combinations for extreme operating conditions were solid lubricating coatings on the tribo-polymer-forming basis and fabric made coatings.

Ball and roller bearings.

What kind of bearings do you work with most often?	
Sliding contact bearings: journal bearings, thrust bearings or collar bearings	27%
Rolling contact bearings: ball bearings or roller bearings	73%

Based on an informal poll sent to 15,000 TLT readers.

Tapered roller bearings and spherical roller bearings.

Thrust bearing pads and journal bearings.

Hydrodynamic journal bearing (it is high load and low speed).

Hybrid bearings with ceramic balls and polyamide cages.

Journal bearings and roller bearings.

Rolling element bearings where we have seen improvements in raceway, cage and element advances for the given applications.

Ball bearings including deep groove, angular contact and four-point contact, and roller bearings including cylindrical, spherical and tapered roller. Many of these bearings have improvements in race geometry and rolling element geometry, raceway and rolling element materials and treatments, cage geometries and materials.

Rolling bearings.

Roller bearings, ball bearings and thrust bearings.

Radial bearings—maintenance-free with various sliding contact surface combinations.

Roller bearings.

Ball bearings for aerospace and medical applications.

All types.

System of rolling ball bearings with the axial clearance compensation by means of wave springs.

Angular contact ball bearings.

Rolling element. The major improvements appear to be coatings that help resist corrosion.

We mostly use plain bearings. To my knowledge there have not been recent performance improvements, but they have so many materials it is difficult/impossible to keep track of.

I have not used any bearings that have new designs.

Hybrid bearings.

Grooves type and rolling type, peak and valley type.

Q.2 What kind of testing machines do you use lately for bearing friction and wear testing?

Handheld FTIR spectrometer, particle counter and grease analyzer.

SRV and FE9.

Dedicated friction test rigs—wear is generally not an issue for rolling bearings.

WAM and FE8.

Vibration, alignment and visual check of grease.

Ball-on-disk tribometer.

None, other than our lab viscometer.

Computational modeling, simulation and tribo-physics exploration.

Most of the bearings that we work on are non-critical. The inspection procedure is to remove clean and visually inspect for corrosion, wear and damage.

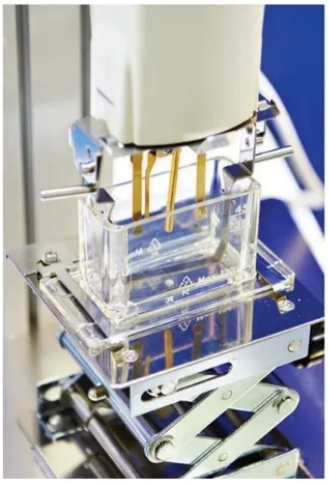
Turboexpander.

What kind of lubricant do you use for your bearings?	
Oil	24%
Grease	41%
Solid lubricant	4%
Combined two or more formats of lubrication	31%

Based on an informal poll sent to 15,000 TLT readers.

Vibe monitoring, bearing metal temperature and bearing oil temperature (on some).

Special test machine having the ability to perform testing of plain bearings with various oscillating characters of sliding.



FE8 and four-ball.

FE8 test rig.

Four-ball test.

We test greases and oils in the FE8 bearing test (angular contact, tapered roller and cylindrical rollers) and grease in the FE9 in angular contact bearings. We also do grease testing in other tapered roller tests such as the KRL. Also we use the ASTM D3336 Pope test with deep groove ball bearings. Other standardized ASTM tests use tapered roller and deep groove ball bearings.

We do not perform our own testing on bearings. Testing is usually performed by the vender or an outside laboratory.

FAG, FE9 and FE8, SRV (linear oscillation test machine) and four-ball test machine.

Four-ball machine (antiwear and extreme pressure [EP] performance).

We use some commercial testers for friction torque and an own-developed combined friction and lifetime bearing test rig. In addition we use model testers like pin-on-disk or ball-on-disk testers at external labs.

Many, several types of machines.

R0F+.

Tribotesters of the ball-on-disk type and of the ball-on-ring with bearing outer race type (partner and counter-partner made from materials of the bearing components) under conditions of lack of lubrication or of lubrication by various oil and greases.

Standard bearing testers of fully assembled bearings, thrust ball and roller bearing testers under marginal lubrication conditions, three-ball on rod and oscillating wear tester.

We test an entire product assembly using a test protocol which imitates actual use. These are prosthetic component industry specific tests. We do not utilize standard friction and wear tests.

FE8 and FE9 test rigs. High speed test rig, false-brinelling test rigs (SNR-FEB2 and Fafnir tester).

Mini traction machine (MTM).

Impact type and sliding type.

Editor's Note: *Sounding Board is based on an informal poll sent to 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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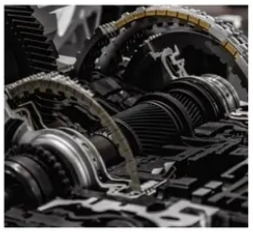

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- Grease
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- Engine & Drivetrain
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- Electric Vehicles

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- Base Oils
- Gears
- Automotive Tribology
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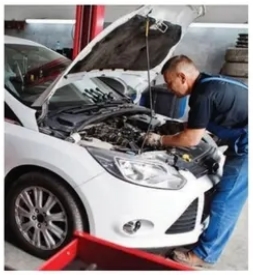

January 2024
Ad close: Nov. 22
Materials: Nov. 30
(2024 STLE Annual Meeting Advance Program provided with this issue!)

- Additives
- Wear
- Condition Monitoring
- Automotive Tribology
- Grease

February 2024
Ad close: Dec. 22
Materials: Dec. 29
(Bonus Distribution: PittCon, Feb. 24-28, San Diego, Calif.)

- Base Oils
- Surface Engineering
- Bearings
- Electric Vehicles
- Automotive Tribology


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RESOURCES

Technical Books

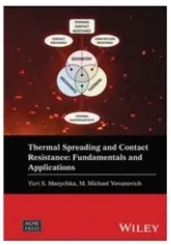
Sustainable Engineering: Process Intensification, Energy Analysis, and Artificial Intelligence

Authors: Yasar Demirel and Marc A. Rosen
Publisher: CRC Press

Sustainable engineering is of great importance for resilient and agile technology and society. This book balances economics, environment and societal elements of sustainable engineering by integrating process intensification, energy analysis and artificial intelligence to reduce production costs and improve the use of material and energy, product quality, safety, societal well-being and water usage. The book provides a comprehensive discussion of topics on process intensification, energy analysis and artificial intelligence that include optimization, energy integration, green engineering, pinch analysis, exergy analysis, feasibility analysis, life cycle assessment, circular economy, bioeconomy, data processing, machine learning, expert systems, digital twins and self-optimized plants for sustainable engineering. Available at **www.routledge.com**. List Price: $190 (USD), hardcover.

Thermal Spreading and Contact Resistance: Fundamentals and Applications

Authors: Yuri S. Muzychka and M. Michael Yovanovich
Publisher: Wiley



"Thermal Spreading and Contact Resistance: Fundamentals and Applications" offers comprehensive coverage of the key information that engineers need to know to understand thermal spreading and contact resistance, including numerous predictive models for determining thermal spreading resistance and contact conductance of mechanical joints and interfaces, plus detailed examples throughout the book. Written by two of the leading experts in the field, this book includes information on contact conductance, mass transfer, transport from super-hydrophobic surfaces, droplet/surface phase change problems and tribology applications such as sliding surfaces and roller bearings; heat transfer in micro-devices and thermal spreaders, orthotropic systems and multi-source applications for electronics thermal management applications; fundamental principles, thermal spreading in isotropic half-space regions, circular flux tubes and disc spreaders; and rectangular flux channels and compound spreaders and systems with non-uniform sink plane conductance, transient spreading resistance and contact resistance between both non-conforming and conforming rough surfaces. Available at **www.wiley.com**. List Price: $140 (USD), hardcover.

Industry Conferences and Events

TriboIndia-2023

Oct. 5-7
Srinagar, India

TriboIndia-2023, International Conference on Tribology, will be at the National Institute of Technology Srinagar, under the Tribology Society of India (TSI), Oct. 5-7. The conference theme is "Sustainable Development through Tribology" and offers a unique platform to discuss the latest advancements in this field. Moreover, eminent experts from industry and academia will deliver plenary and keynote lectures. Key topics include nanomechanical testing and nanotribology, artificial intelligence-based maintenance in Industry 4.0, extreme environment tribology, tribology of electric vehicles, tribology for sustainability, space tribology, biotribology and more. For more information, visit **http://tribologyindia.org**.

European Base Oils & Lubricants Summit

Nov. 15-16
Barcelona, Spain

The 2023 European Base Oils & Lubricants Summit is Nov. 15-16 in Barcelona, Spain. It will bring together senior experts from the base oil and lubricants industry, including lubricant manufacturers, base oil producers, additive suppliers, technology and service providers, trading and distribution companies, OEMs and packaging and logistic companies to discuss current industry news and topics, including sourcing new materials, wind turbine developments, e-mobility and more. For more information, visit **www.wplgroup.com/aci/event/base-oils-lubricants-summit/**.

TriboBr2023

Nov. 26-30
Vitoria, Brazil

The Fourth International Brazilian Conference on Tribology (TriboBr2023) will bring together world-renowned experts in tribology research and application to ▶

Industry Conferences and Events *(continued)*

discuss state-of-the-art developments and future trends in the field, with a particular focus on the role of tribology in the energy transition. The conference will provide researchers and practitioners with a unique opportunity to exchange information, present new developments, establish new international personal networks and discuss the future directions and priorities of tribology. It also will feature a special focus on how research on tribology can help reduce energy consumption and improve sustainability. For more information, visit **www.tribobr2023.com.br/**.

ILMA 6th International Metalworking Fluids Conference

Jan. 8-10, 2024
Atlanta, Ga.

The Independent Lubricant Manufacturers Association (ILMA) is hosting the **6th International Metalworking Fluids Conference**, Jan. 8-10, 2024, in Atlanta, Ga. Challenges continue for raw material suppliers, manufacturers and end-users of metalworking fluids (MWFs). This conference intends to help attendees meet these challenges by calling on industry experts to cover the following key topics: sustainability: end-user's perspective, impact of electric vehicles on MWF demand and use, best practices for managing MWFs in the plant, new techniques for evaluating MWFs in the lab, remote monitoring of MWF, supply chain challenges, sustainable MWFs, biocides: how to work with their dwindling number, regulations impacting MWF use including PFAS restrictions, health and safety effects of MWFs and additive challenges. For more information, visit **www.mwfconference.org**.

STATEMENT OF OWNERSHIP MANAGEMENT AND CIRCULATION

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B2.	Paid in-county subscriptions	0	0
B3.	Sales through dealers and carriers, street vendors, counter sales and other non-USPS paid distribution	903	910
B4.	Other classes mailed through the USPS	137	3
C.	Total paid and/or requested circulation	4,539	4,380
D1.	Outside-county as stated on Form 3541	0	0
D2.	In-county as stated on Form 3541	0	0
D3.	Other classes mailed through USPS	0	0
D4.	Free distribution outside the mail	543	228
E.	Free distribution outside the mail	543	228
F.	Total free distribution	5,082	4,608
G.	Copies not distributed	0	0
H.	Total	5,082	4,608
I.	Percent paid and/or requested circulation	89.3%	95.1%

16. This statement of ownership will be printed in the October 2023 issue of this publication.
17. I certify that the statements made by me above are correct and complete:
(Signed) Rachel Fowler, Publisher/Editor-In-Chief, 10/1/23


November 12 - 15, 2023
STLE Tribology Frontiers Conference
Co-Branded Event
November 12-15, 2023
Cleveland Marriott Downtown at Key Tower, Cleveland, Ohio (USA)
November 14 - 15, 2023
Tribology & Lubrication for E-Mobility Conference
A co-branded event
STLE Tribology Frontiers Conference
Learn about the technical, environmental and social issues impacting tribology research in the 21st Century.
Conference Highlights:
• Daily keynote presentations
• Invited "Spotlight" talks by noted principal investigators
• Artificial intelligence (AI) and machine learning in tribology session
• Graduate, undergraduate and early career researcher poster competition
• "Beyond the Cutting Edge" special symposium (organized by the editors of Tribology Letters)
STLE Tribology & Lubrication for E-Mobility Conference
Explore the latest technical challenges and opportunities impacting the future of electric vehicle technology.
Conference Highlights:
• Expert-led presentations from leading companies and organizations with an interest in e-mobility
• Panel discussions on state-of-the-art developments in electric vehicle technology and lubrication
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AUTOMOTIVE TRIBOLOGY

Electric vehicles off the grid

An electric vehicle can work as a primary means of transportation most of the time, but what about during a power outage?

By Dr. Edward Becker
Contributing Editor

While my wife and I could hardly be considered early adopters of the technology, we did purchase our first battery electric vehicle (BEV) earlier this year. It has become our primary form of transportation around town and around the metro area. However, I thought our recent experience might be worth sharing.

On a Thursday in the past month or so, a storm resulted in widespread power outages all around lower Michigan. Estimates for when the power would be restored ranged from several hours to several days, so we really didn't know how long we would be off the grid. We had been using the BEV rather extensively that day, and when the power went off, we were down to 60 miles (97 km) of range left.

Fortunately, we had prepared our home (to some degree) by installing solar panels on the roof and adding a back-up battery in the garage. Both were expensive, to be sure, but we intend to stay in this location for a very long time, and the savings on utility costs will pay back the investment within a decade or so. Also, the battery provides a degree of emergency power sufficient for some (but not all, as I will explain in a moment) of our electricity needs.

Before we do some basic arithmetic, a few numbers and constraints are in order. The solar panels produce anywhere from zero (when the sun is not shining) to about 4 kW at noon on a sunny day, with an average output of about 20 kWh per day in the summer. The battery will hold 10 kWh and can discharge at 3 kW maximum. Our electric vehicle has a 65 kWh battery. The Level 2 charger we have installed in our garage requires 12 kW of power, while the Level 1 charger requires 1.1 kW.

Although BEVs are becoming more popular, they are still not for everyone.

We quickly discovered that the total output of the solar panels and the battery was insufficient to run the Level 2 charger (and if it did work, would have depleted the home battery to zero in a few minutes, leaving us with no power for the home). While the Level 1 would work, it took 1.1 kW and added less than 5 miles (8 km) of range per hour. Even so, we tried to only use the Level 1 charger while the solar panels were generating over 1 kW, to avoid depleting the home battery.

To charge the BEV from a fully depleted to fully charged state with the Level 1 charger would have required about 60 hours (about 2.5 days), while the Level 2 charger would accomplish the same task in about five hours. By carefully managing the Level 1 charger, and limiting our travel to only a few miles from home, we were able to live fairly normal lives while the power was out, in spite of having to limit the use of high wattage appliances. The outage lasted two days, and we were even fairly popular with the neighbors, who came over to charge their tablets and cell phones during the day!

Also, our second car is a gasoline-fueled vehicle, so we could have traveled further if necessary. Bottom line, we are still very happy with our BEV, but only because we are fortunate enough to have a second (gasoline-fueled) car, a home with a place to have a Level 2 charger and a back-up electrical system for when the grid fails. So, although BEVs are becoming more popular, they are still not for everyone, particularly those without access to a Level 2 charger at home or a back-up source of electricity during power failures!

Ed Becker is a Fellow and Past President of STLE. He is currently president of Friction & Wear Solutions, LLC and can be reached through his website at ***www.frictionandwearsolutions.com****.*

Nominations now being accepted for 2024 STLE Awards Program

2023 P.M. Ku Award Winners
Paul Hetherington and
Greg Croce

Each year STLE honors individuals for outstanding achievements in the field of tribology and lubrication engineering. The Society is now accepting nominations for its two prestigious honors: The STLE International and P.M. Ku Awards, which will be presented during the 78th STLE Annual Meeting & Exhibition in Minneapolis, Minnesota (USA), May 19-23, 2024.

The STLE International Award is the Society's highest technical honor and bestows lifetime honorary membership on the recipient, who need not have been a member of STLE. It is given in recognition of the recipient's outstanding contributions in tribology, lubrication engineering or allied fields.

The P.M. Ku Award recognizes outstanding and selfless achievements on behalf of the Society. It is given to an STLE member who most typifies the dedicated spirit of the late P.M. Ku, who worked tirelessly to promote and advance the mission of STLE.

Nominations deadline is Dec. 1, 2023.

Nominations must include all required letters and documentation for consideration.

To fill out the forms, go to **https://stle.submittable.com/submit**.

For more information about the STLE Awards Program, visit **www.stle.org/awards** or contact Karl Phipps, ***kphipps@stle.org***.

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CUTTING EDGE

Does molecular branching control boundary lubrication?

Resonant frictional measurements as a function of film thickness reveal how the branching of organic molecules influences their molecular ordering near the surface and the transition from hydrodynamic to boundary lubrication.

By Drs. Wilfred T. Tysoe & Nicholas D. Spencer
Contributing Editors

Lower-viscosity fluids are preferred for lubricants that operate under hydrodynamic (fluid-film) lubrication conditions at high sliding speeds (V) and low loads (L). This leads to low friction when the V/L ratio is large, according to the well-known Stribeck curve. The downside is that such low-viscosity fluids have a greater tendency to stray into the higher-friction boundary-lubrication regime as V/L decreases. The conventional explanation for this transition from the hydrodynamic to the boundary-lubrication regime is that the film thickness decreases below the surface roughness, allowing the interfacial asperities to contact to cause the friction to increase as the velocity decreases and/or the load increases. An alternative molecular-scale explanation has been proposed: that the friction increase is due to the formation of a compact, solid-like, very viscous layer as the film thickness decreases. If this is the case, it should be possible to control the transition from the hydrodynamic to the boundary lubrication regime simply by controlling the molecular structure of the lubricant.

Professors Kazue Kurihara and Masashi Mizukami from Tohoku University in Sendai, Japan, in collaboration with Dr. Masanori Iizuka of the Nissan Chemical Corp. in Funabashi, Japan, tested this postulate by comparing the tribological properties of a planar molecule, hexadecane, which is more likely to pack into a solid-like layer, with branched molecules, isosteric acid and isosteric acid T (a mixture of two branched carboxylic acids), which are expected to order less easily. They also compared their results with those from a poly (α-olefin) (PAO)—a model, branched synthetic lubricant.

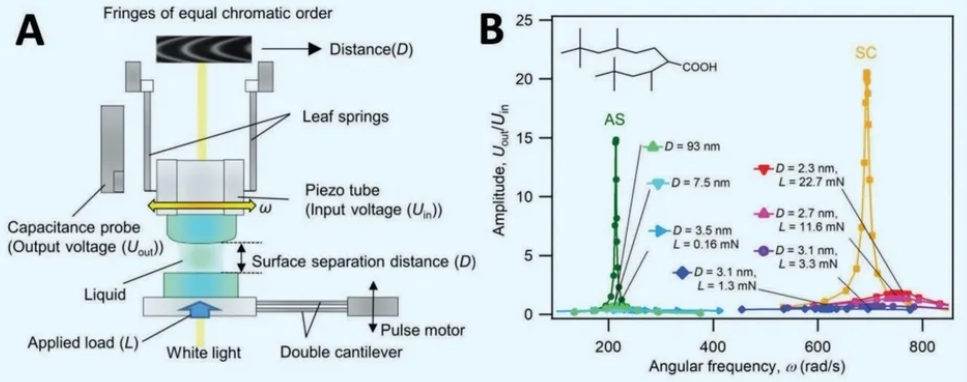

Figure 1. **a.) Schematic drawing of the resonance shear measurement system. b.) Resonance curves of isostearic acid confined between mica surfaces, which also show results for the surfaces separated by air (AS), corresponding to no friction and for mica sheets in direct contact (SC), i.e., a "no-sliding" condition. The numbers indicated within the plots show the separation (D) and load (L).** *Published with permission from Ref 1.*

The researchers carried out their nanotribological measurements with a modified surface-forces apparatus *(see Figure 1a)*, which uses atomically flat mica surfaces and can measure the distance between them by interferometry. They measured the frictional properties by rapidly shearing the contact and measuring the response as a function of driving frequency. Figure 1b shows typical results that illustrate the expected resonant behavior, which can be analyzed to yield values of a viscosity parameter, b_s. The measurements were made for all fluids as a function of film thickness down to values smaller than molecular dimensions.

It should be possible to control the transition from the hydrodynamic to the boundary-lubrication regime simply by controlling the molecular structure of the lubricant.

The resulting measured values of the viscosity parameters are plotted as a function of the film thickness in Figure 2. The film close to the surface is much more viscous than the bulk.

The measured values are summarized in Table 1 along with the hard-wall distances, D_{HW}, of all molecules. First, the b_s values at large distances correlate well with the bulk viscosities of the fluids; the bulk viscosity controls the bulk friction as expected for hydrodynamic lubrication. However, the viscosity increases dramatically close to the surface where the fluid with the lowest bulk viscosity (hexadecane) has the most viscous surface film. Similarly, the branched chains have a lower viscosity for thicknesses at the hard-wall separation than for hexadecane, but much higher than in the bulk, suggesting that they are still ordered. The trends accord very nicely with the postulate that closer packing leads to denser and more viscous boundary films that exhibit high friction.

Thus, while roughness effects undoubtedly still play a role in the transition from the hydrodynamic to the boundary lubrication regimes, these results show that such effects may be mitigated or even avoided by the judicious choice of the molecular structure of the lubricating fluid.

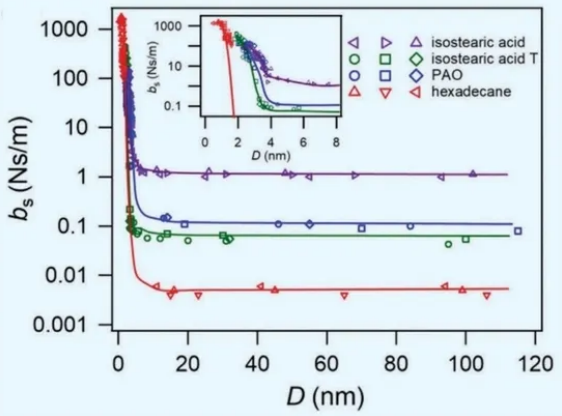

Figure 2. **Viscosity parameters (b_s) of isostearic acid, isostearic acid T, PAO and hexadecane as a function of the film thickness, D. The solid lines are included as a guide to the eye. The insets show magnifications of the plots at short distances.** *Published with permission from Ref 1.*

Table 1. **Selected parameters of the investigated liquids**

Sample	b_s at large D (~ 100 nm) (Ns/m)	b_s at D_{HW} (Ns/m)	D_{HW} (nm)
Isostearic acid	1.06 ± 0.07	106 ± 21	2.4 ± 0.1
Isostearic acid T	0.049 ± 0.006	282 ± 52	1.9 ± 0.1
PAO	0.100 ± 0.008	134 ± 5	2.3 ± 0.2
Hexadecane	0.005 ± 0.001	1550 ± 147	0.7 ± 0.2

Eddy Tysoe is a distinguished professor of physical chemistry at the University of Wisconsin-Milwaukee. You can reach him at ***wtt@uwm.edu.***

Nic Spencer is emeritus professor of surface science and technology at the ETH Zurich, Switzerland, and editor-in-chief of the STLE-affiliated Tribology Letters journal. You can reach him at ***nspencer@ethz.ch.***

1. Iizuka, M., Masashi, M. and Kurihara, K. (2023), "A macro and nanoconfined tribological study of linear and branched molecules," *Tribology Letters*, **71**, p. 71.

LUBRICANT INDUSTRY CAREER OPPORTUNITIES

Pelichem has 45 years of recruitment experience and is dedicated to serving clients globally in **lubricant and additive industries**. According to ADP reports, the U.S. economy grew at a strong pace from 2017 through 2019 with an average of 200,000 private sector monthly job gains. The COVID-19 pandemic halted U.S. economic growth in April 2020 with the loss of 19.4 million private sector jobs. The economy has since been recovering at a strong pace with private sector job growth of 10 million jobs from May through December 2020, 500,000+ average monthly job gains in 2021, 200,000+ average monthly job gains in 2022, and 260,000+ average monthly job gains from January through July 2023. Several career opportunities with client companies are listed below.

APPLICATIONS TECHNOLOGY MANAGER / TECHNICAL SERVICE
(Southern Region)

Leading family-owned, international manufacturer of high-performance synthetic esters is seeking an experienced lubricants formulator. This person will manage a small team of technicians in product formulation and applications troubleshooting. The position includes regular interaction with the sales force, business team, and customers.

SENIOR SYNTHESIS CHEMIST
(Midwest Region)

Well-established manufacturer of a diverse line of alkanes, polymer additives, antioxidants, and lubricant additives is searching for an experienced chemist to conduct product and process development studies to introduce new products into production. This individual will perform studies in an R&D synthesis lab with focus on improvement of products and processes, and on laboratory to pilot plant to full scale trials.

SCIENTIST – METALWORKING FLUIDS
(Midwest Region)

Large, international manufacturer of lubricants is seeking a scientist to conduct R&D on a broad line of water-based and oil-based metalworking lubricants. This position involves project management, development of new products, and bench tests. The successful candidate will collaborate with the global technical community to discover new technologies, formula bases, raw materials and processing techniques that lead to unique products.

SALES MANAGER – INDUSTRIAL LUBRICANTS
(Midwest Region)

Long-established, family-owned distributor for a diverse line of commercial and industrial lubricants has created a new sales management role due to 25% average sales growth in recent years. This position reports to the President and is responsible for directing the activities of a well-experienced sales force of 10 representatives. Fleet and manufacturing markets are the primary focus. Minimal overnight travel.

ACCOUNT MANAGER – SPECIALTY PRODUCTS
(Texas Region)

Major, well-established multi-line chemical distributor has created a new position for a technical sales professional in base oils and additives for automotive and industrial lubricant applications. This position may start as a hybrid role (inside and outside) but will quickly lead to managing an outside sales territory.

Please call or send resume at your earliest convenience if you are considering a new position. Your response will be handled promptly and with the utmost confidentiality.

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www.pelichemsearch.com

By Don Smolenski
Contributing Editor

In June of 2023 in southeast Michigan, we experienced extremely hazy air caused by soot from Canadian wildfires. It was a serious issue resulting in alerts that the air quality was dangerous for the higher risk population (people with heart or lung issues, immune compromised people, the elderly, etc.). It was unhealthy, though, for the entire population. Fortunately, it only lasted a few weeks. People in many areas live with this, and other types of pollution, every day, and it is taking its toll. Air, water and occupational pollution was responsible for 15% of all deaths globally in 2017.[1,2] 2019 is even more dire.

Table 1 shows the top 10 countries for total premature pollution-related deaths. India and China lead with the most deaths. Very surprisingly, the U.S., with the world's third largest population at 325 million, cracks the top 10 with nearly 200,000 pollution-related deaths.

Table 2 shows the top 10 countries for pollution-related deaths per 100,000 population. Many of the top 10 countries are poorer, smaller countries, but some are larger and more affluent. The Lancet Commission on pollution and health concluded that one in six deaths globally are caused by pollution, and ambient air pollution is the leading cause of death. Air pollution, both ambient and indoor, was deemed responsible for half of the pollution-related deaths in the U.S. in 2017. According to Dr. Jack Caravanos, professor at NYU College of Global Public Health, "Pollution doesn't get the resources commensurate with the impact. It is difficult to trace deaths to pollution because there are so many types and end results."

One in six deaths globally are caused by pollution, and ambient air pollution is the leading cause of death.

Pollution also is complicit in disability impacts, and these are undercounted. Disability-adjusted life years (DALYs) is an internationally recognized measure of overall disease burden. Currently, there are 275 million DALYs. Pollution of all types is claimed to cause 21% of deaths from cardiovascular disease, 26% from ischemic heart disease, 23% of stroke deaths, 51% of chronic obstructive pulmonary disease (COPD) deaths and 43% of lung cancer deaths. Pretty concerning! Look for more detail on the types of pollution and the diseases they cause in a future column.

Don Smolenski is president of his own consultancy, Strategic Management of Oil, LLC, in St. Clair Shores, Mich. You can reach him at ***donald.smolenski@gmail.com****.*

1. Hogue, C. (May 23, 2022), "Pollution kills 9 million people a year, report says," *Chemical and Engineering News*, American Chemical Society. Available at **https://cen.acs.org/environment/pollution/Pollution-kills-9-million-people/100/i18**.
2. "New Report, Pollution and Health Metrics: Global, Regional and Country Analysis," Global Alliance on Health and Pollution. Available at **https://gahp.net/pollution-and-health-metrics/**.

Table 1. **Top 10 countries with premature pollution-related deaths[2]**

Rank	Country	Total annual premature pollution-related deaths
1	India	2,326,771
2	China	1,865,566
3	Nigeria	279,318
4	Indonesia	232,974
5	Pakistan	223,836
6	Bangladesh	207,922
7	USA	196,930
8	Russian Fed.	118,687
9	Ethiopia	110,787
10	Brazil	109,438

Table 2. **Top 10 countries for pollution-related deaths per 100,000 population[2]**

Rank	Country	Pollution deaths per 100,000 people
1	Chad	287
2	Central African Rep.	251
3	North Korea	202
4	Niger	192
5	Madagascar	183
6	Papua New Guinea	183
7	South Sudan	180
8	Somalia	179
9	Serbia	175
10	India	174