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Q&A with Rexnord’s Robin Olson

**Tribological Systems**
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Our year in review

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This past year was STLE’s year with me, Mike Anderson, as president. And what a year it has been!

Never had I dreamed of being president of such a distinguished organization when I attended my first Chicago Section meeting in 1979 shortly after graduation. Nor did I ever think that I would be involved in tribology 40 years later.

But this year was very special. As president, I visited and made presentations in 12 foreign countries and several locations in the U.S. in the promotion of STLE and tribology-related activities. Along with establishing a presence in China and Europe, these activities are confirming STLE’s vision of becoming the global leader in advancing the science of tribology.

As president of STLE I have had the opportunity to meet and work with some of the greatest tribologists in the world, many of whom are attending this year’s annual meeting in Minneapolis. This year brought about a lot of exciting new activities to STLE: the Jeanie S. McCoy Scholarship for promoting females to enter the field of tribology studies, participation in Latin America, the STLE 365 Mobile App, certification exams in Spanish, Learning Pathways for enhanced education, introduction of a scholarship-funding program, the updated STLE Emerging Trends Report and the LimeLight project to work with other organizations in exposing tribology that exists in their industries and the new Foundations of Lubrication Engineering transportable education course.

Spreading tribology and STLE is a major part of being president. During the year, STLE Vice President Greg Croce and I met with a group of engineers in Bangkok interested in forming a local section under STLE. At the same meeting, various attendees were interested in forming a local presence in Singapore. The highlight of the Asia trip was attending the 6th World Tribology Conference in Beijing, China. More than 2,000 tribologists and young engineers attended, presented papers and participated in an Olympic-style event complete with opening and closing ceremonies done on a grand scale. The event was assisted by more than 150 volunteers, including over 100 students who are now studying to become our industry’s future tribologists. This was certainly an awesome experience to be remembered my whole life. During the same time, STLE participated in two other major tribological events in China: the 18th International Chinese Lubricant and Technology Exhibition and the Chinese Lubricant and Technology Forum. Cutting the opening ceremony ribbon at the exhibition...
was quite the experience. STLE’s participation further confirms its desire to be a part of the growing Asian movement in tribology.

In January 2018 STLE participated in the 21st meeting of the prestigious International Colloquium Tribology at Technische Akademie Esslingen in Germany. This event is held every two years and features tribology-related papers, networking opportunities and activities, including a plant tour of a local car manufacturing assembly plant. As STLE president I participated as a speaker in the plenary session with a presentation that asks: “Can Tribology Save the World?” At the end of the presentation, it was clear; everyone agreed that indeed tribology can save the world. Tribology cannot create energy, but it can reduce its need through friction reduction, development of longer-lasting wear resistant materials and new, energy-conserving designs.

Closer to home, STLE has become quite active in Latin America. STLE has entered into a memorandum of understanding with a local STLE member to support a series of education seminars that promote tribology in Central America. Local industrial professionals and university students attend these seminars with upward of 350 attendees. By interacting with the students and appreciating their intermediate and long-term goals for success, STLE is working on developing a better platform for these students to interact with universities offering programs in tribology. Additionally it will help them to network with potential employers and students in other parts of the world. The Emerging Trends Report has identified the lack of well-trained young professionals entering our field as a major industry imperative. Assisting these students could fill this need and help them to become a part of the future of tribology.

Riding on the back of the successful German translation for the Certified Lubrication Specialist™ (CLS) exam, STLE has translated both the CLS and Certified Oil Monitoring Analyst™ (OMA I) exams into Spanish and will be offering these exams in Spanish at future Latin American seminars.

This year’s annual meeting, our 73rd, is in Minneapolis and brings to an end my term as president. It has been a busy and incredibly rewarding year. I will miss all the activities of being president, but the future of STLE is in good hands with 2018-2019 President Croce and the board members who will support him in his duties. I plan to continue supporting STLE in areas where I can best offer my services.

At this time I wish to thank Falex Corp., including Andrew Faville, Leslie Heerdt, Thomas Peterson and James Hepp for their corporate and personal support of my activities as president. Their financial contribution to my STLE presidency affirms their dedication to STLE and their belief that the world will be a better place because of tribology.

I also wish to thank the members of STLE for your comments on my columns, the warm receptions received on our section and corporate member visits and for your past and future financial support of STLE activities through member dues and contributions. This is your society and, like me, you want to see it grow and improve. And as long as there is friction and wear in the world, tribology has a place.

I don’t know what the future will bring, but you can be sure that tribology will be a part it. As I have said in every one of my columns, “Tribology, it’s everywhere!”
At the turn of the last century, rancher Samuel Burk Burnett established the Four Sixes (6666) Ranch, some of which rested on land leased from the Comanche. When the federal government ordered the land turned back to the tribes, Burnett traveled to Washington to meet President Theodore Roosevelt who then granted all ranchers a two-year extension on their leases.

In the spring of 1905, during a visit to the lands and ranchers he had helped, Roosevelt was entertained by Burnett at his home near Nesterville, Texas, where they participated in a bare-handed wolf and coyote hunt. Their friendship grew over the years, so much so that during a visit in 1910 Roosevelt suggested the town be renamed Burkburnett in his honor.

On July 29, 1918, just outside of town on S.L. Fowler’s farm, a wildcat well struck oil at 1,734 feet. Just three weeks later there were 56 drilling rigs in operation, and by June 1919 there were more than 850 producing wells, earning Burkburnett the nickname of Boomtown, USA.

This time period was immortalized in song and story; the most well-known version appeared in the August 1939 issue of Cosmopolitan magazine entitled A Lady Comes to Burkburnett, written by James Edward Grant. This short story served as the inspiration for the 1940 film Boom Town, starring Clark Gable and Spencer Tracy as fellow wildcatters.

One of the other permanent markers of the time sits just a little way south in downtown Wichita Falls. In the wake of booming business, oilmen were desperate for office space, and they thought they found their answer with a con man out of Philadelphia: J.D. McMahon. McMahon’s oil-rig construction firm was a tenant of the Newby Building, a single-story brick building near the railway depot. McMahon proposed that he construct a high-rise annex to add some much-needed office space. He managed to wrangle $200,000 from investors (almost $3 million today) using blueprints drafted with a very clever mistake.

What investors saw listed for height was mistaken as 480’ (feet), when the reality was actually 480” (inches). By using his own crew, the building was nearly complete before the investors realized they had been taken. They took him to court, but since the blueprints matched the finished product the court ruled in McMahon’s favor.

To make things worse, the crew originally contracted for the elevator backed out, so the only way to access the upper floors was an external ladder. Years later, an internal stairwell was added, occupying approximately a quarter of the already cramped 11’ by 19’ footprint of the building.

Left without recourse, oil companies moved into the office space until the boom died down a few years later. By the time the Depression hit, the building had been vacated and boarded up. After a fire gutted the building in 1931 it became unusable and sat for decades.

Once the economy recovered, the building was occupied briefly by a barbershop and cafés but continued to change hands. Though it was slated for demolition, it avoided this fate and was deeded to the city. After years of further deterioration, the city gave the building to the local historical society in hope that it might carry out a restoration. By 1999 the society could no longer afford to keep the building.

In 2000 a local architectural firm was hired by city council to stabilize the structure. The firm partnered with another local business and purchased the building. Delayed by storm damage in 2003, the building was finally restored in 2005 and re-opened.

Known as the “world’s littlest skyscraper,” the Newby-McMahon building sits as a reminder of a bygone era of fast money and fast talkers.

By Evan Zabawski

Evan Zabawski, CLS, is the senior technical advisor for TestOil in Calgary, Alberta, Canada. You can reach him at ezabawski@testoil.com.
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What do I get with my membership?

Membership offers many benefits. The ability to say you’re part of an organization with high ethical standards is one of them.

By Edward P. Salek, CAE
Executive Director

Throughout our nearly 75 years of existence, STLE has built a reputation as the premier technical organization for tribology and lubricants. We support that reputation by advancing innovation in the field, helping people gain technical expertise and by being a global advocate for the profession.

But STLE’s impact stretches beyond these areas to include serving as a leader in establishing high standards that guide the ethical interaction of companies and people who have chosen to become members of the organization. This guidance comes from a series of governance and policy statements that have been established by past STLE Boards of Directors and which are curated by the current leadership.

Under these rules, a member’s relationship with the society is established by a portion of the STLE Constitution and Bylaws. The statement commits members to “abide by the Constitution and Bylaws, the Code of Conduct and other rules and regulations as the Society may adopt.”

The referenced Code of Conduct explains what it means for members to act in a “professional manner marked by integrity and a spirit of fair play.” It’s comprised of nine statements on topics that govern activities in areas including protection of competitive or corporate information, confidentiality commitments and proprietary information. The code also encourages trust and honest exchange between peers by encouraging members to “answer truthfully all non-competitive questions and inquiries from the society or any member.”

The Constitution and Bylaws, Code of Conduct and other policies described in this column are available for review at www.stle.org under the About tab.

Two newer policies deal with issues that are receiving more intense interest and scrutiny every day. One is a Harassment Policy for Program and Activities, which relates to personal interactions. It states in part, “STLE is committed to providing an atmosphere that encourages the free expression and exchange of scientific ideas. As part of that commitment, it is dedicated to promoting an environment that is safe and comfortable for all participants in society-related programs and activities and that encourages respect for the dignity of each individual.”

A privacy statement, second of the two policies, confronts digital age concerns about the collection and dissemination of personal information through the Website or other means. There also is a social media aspect of the policy that seeks to assure that Facebook or LinkedIn sites sponsored by STLE serve as responsible forums for discussion on issues related to tribology and lubrication engineering.

STLE’s logo on your business card tells customers, vendors and colleagues that you have agreed to a set of codified principles dedicated to professionalism, honesty and fair play.

Members who abide by these policies earn a unique privilege of membership. You may use the STLE name, acronym and logo on letterhead and business cards, provided such reference does not indicate, directly or indirectly, endorsement by STLE of the member’s business, services or products.

Members also may use the STLE name, acronym and logo in print and Web advertising, provided the same requirements are met. Details about proper usage of the name and logo are also outlined in a policy that appears on www.stle.org.

Several hundred years ago, U.S. President Thomas Jefferson advised his contemporaries, “On matters of style, swim with the current, on matters of principle, stand like a rock.” In today’s world, STLE is proud to be the rock that technical professionals can identify with to show their commitment to fair and responsible ways of doing business.

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Greg Croce, Delo Brand technical manager for Chevron Products Co. in Richmond, Calif., takes the reins as STLE’s 2018-2019 president. His one-year term begins at STLE’s 2018 Annual Meeting & Exhibition, May 20-24, at the Minneapolis Convention Center in Minneapolis, Minn. (USA).

Croce received his bachelor’s of science degree in chemical engineering and an MBA from the California State Polytechnic University, Pomona. He first worked as an analytical chemist for Weck Laboratories and then a process engineer and manager of engineering for Technip USA/KTI, where he was a combustion engineer designing fired heaters.

In 2000 Croce joined Chevron as a global account manager/OEM service engineer. At Chevron he has held several positions including North American product line specialist, regional sales manager for Techron, base oil optimization specialist, product line manager for global marine and his current assignment.

In 2005 Croce joined STLE’s Board of Directors, and in 2015 he joined the Executive Committee, serving one-year terms as treasurer, secretary and vice president. He officially becomes president on May 22 at the annual STLE Presidents Luncheon & Business Meeting. Joining him on the Executive Committee are Vice President Dr. Michael Duncan (Daubert Chemical Co.), Secretary Paul Hetherington (Petro-Canada Lubricants Inc.), Treasurer Dr. Ken Hope (Chevron Phillips Chemical Co. LP) and STLE Executive Director Ed Salek.
Ken Hope, global PAO technical services manager for Chevron Phillips Chemical Co. LP in The Woodlands, Texas, is slated to join STLE’s Executive Committee. Hope graduated with a doctorate in physical chemistry from the University of Alabama at Birmingham in 1988.

Hope has more than 25 years of experience in the lubricant industry. His research interests have been primarily focused in the area of polyalphaolefins and the use of synthetic lubricants. Prior to becoming global PAO technical services manager for Chevron Phillips Chemical Co., he was a research fellow and team leader for NAO and PAO Research and Technology responsible for the product development, process improvement and technical service for NAO and PAO product lines. He also has been responsible for acetylene black and the pilot plant operations for Chevron. For several years he worked in the analytical group at Chevron doing NMR research on catalysts and structure/property relationships on various materials. Before joining Chevron he was the director of the NMR Research in the chemistry department at the University of Houston.

Hope served on the STLE Board of Directors from 2006 to 2017. He has organized the Lube School in Houston and participated as an instructor for the Houston, Chicago and Oklahoma Local Sections. For the past 15 years, he instructed the synthetics part of the Basic Lubrication course at STLE’s annual meeting. He also holds STLE’s Certified Lubrication Specialist™ designation.

A former chair of STLE’s Editorial & Publications Committee, Hope has served on the editorial board of the Journal of Lubrication Science and as a TLT Technical Editor. He also has served as a member of the API Base Oil Interchange/Viscosity Grade Read Across Task Force as well as ASTM and SAE. He has presented technical papers at STLE, NLGI, AICHE and SAE meetings and holds 18 U.S. patents.
Meet STLE’s Newest Board Members

Members have elected the following to STLE’s 2018-2019 Board of Directors:

Dr. Aaron Greco, Argonne National Laboratory in Lemont, Ill.
Dr. Robert Jackson, Auburn University in Auburn, Ala.
Dr. Farrukh Qureshi, The Lubrizol Corp. in Wickliffe, Ohio.

All three begin their terms at STLE’s 2018 Annual Meeting & Exhibition in Minneapolis, Minn. (USA).

Greco is the manager of the Materials for Harsh Conditions Group at Argonne National Laboratory where he leads a team of scientists and engineers on research related to investigation of drivetrain failure mechanisms, advanced materials and manufacturing technology, development of advanced coatings and investigation of the fundamentals of materials tribology. Prior to this Greco held positions at the U.S. Department of Energy Wind Energy Technology Office and The National Academies as a science policy fellow.

Greco has more than 14 years of experience in the field of tribology, specifically in the areas of contact failure analysis, surface engineering and nanoparticle lubricant additives. Greco has been involved with STLE since 2004 and has served on the Tribology Frontiers Conference’s Planning and Awards Committees. He has been an STLE Annual Meeting technical session chair and associate editor of Tribology Transactions. He has received STLE honors for publishing excellence and poster presentations, a scholarship from the STLE Chicago Section and the ASME Burt L. Newkirk Award. Greco received his bachelor’s of science degree from Iowa State University and doctorate degree from Northwestern University, both in mechanical engineering.

Jackson is the director of the Tribology Program and a professor of mechanical engineering at Auburn University. He received his doctorate in mechanical engineering at the Georgia Institute of Technology in Atlanta. He has made significant contributions in the areas of rough surface contact mechanics, contact resistance, multi-physics modeling and nanoparticle lubricant additives. Jackson and the laboratory are internationally recognized as indicated by having more than 80 refereed journal publications, 135 conference papers and presentations and three book chapters.

At Auburn University, Jackson has established the Multiscale Tribology Laboratory, which focuses on the areas of friction, contact, wear and lubrication (tribology). In 2012 Jackson also initiated the first undergraduate Minor degree program in the field of tribology. Jackson received the 2011 ASME Burt L. Newkirk Award for notable contributions to the field of tribology as indicated by significant publications before reaching the age of 40, the 2009 STLE Captain Alfred E. Hunt Memorial Award for the best paper in the field of lubrication and the 2009 Earle Shobert Prize Paper Award at the Holm Conference on Electrical Contacts. He also was named the best reviewer for the ASME Journal of Tribology in 2008 and 2009. In 2013 Jackson was awarded the Auburn University Mark A. Spencer Creative Mentorship Award for advising of undergraduate student Ryan Whitmore.

Qureshi is a technical fellow in the applied sciences department in R&D at The Lubrizol Corp. His current areas of research include engine and driveline tribology, lubrication of hybrid vehicle systems, fuel economy and durability.

Qureshi earned his doctorate in mechanical engineering from Georgia Institute of Technology in Atlanta. He joined Lubrizol’s corporate research and development in 1998 and has been providing global tribology leadership for Lubrizol Additives. He has been an STLE member since 1998 and is an STLE Fellow. He served in various STLE volunteer positions from paper solicitation chair to chair of the Annual Meeting Planning Committee. He has more than 50 peer-reviewed presentations and publications.
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STLE wishes to thank the following sponsors for their generous support of the 2018 STLE Annual Meeting & Exhibition, May 20-24, at the Minneapolis Convention Center in Minneapolis, Minn. New sponsors are arriving every day, so please see the STLE Annual Meeting Program Guide distributed on site and signage in Minneapolis for the most up-to-date information. This information also appears in the Annual Meeting section of the STLE 365 App. The Annual Meeting section of the app is sponsored by Focus Chemical and contains the latest information and any alerts relating to the trade show. Download the app from The App Store (Apple products) or The Play Store (Android products), or just scan this QR code:

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Make time to visit these exhibitors at STLE’s 2018 trade show in Minneapolis.

The following exhibitors are displaying the lubricant industry’s latest products, services and technologies at STLE’s 73rd Annual Meeting & Exhibition, May 20-24, at the Minneapolis Convention Center in Minneapolis, Minn. The trade show, May 21-23, is another STLE service designed to help you maintain your status as a leading technical professional.

STLE is sponsoring Exhibitor Appreciation Hours on Monday and Tuesday, May 21 and 22, from 3-4 p.m. Refreshments will be served, and the trade show is the only annual meeting activity conducted during that time. Evonik Oil Additives is sponsoring raffles on Monday and Tuesday during both Exhibitor Appreciation Hours, and you must be present at their Booth 103 to win. Evonik is raffling three Fitbit Alta fitness trackers.

This list is complete through April 25 and will be republished in the Annual Meeting Program Guide distributed on site in Minneapolis. The list also is available in the Annual Meeting section of the STLE 365 App. The Annual Meeting section of the app is sponsored by Focus Chemical and contains the latest information and any alerts relating to the trade show. Download the app from The App Store (Apple products) or The Play Store (Android products), or just scan this QR code:

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### 2018 STLE Exhibition Booth Assignments

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<th>Company Name</th>
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<td>MUNZING</td>
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<td>Napoleon Engineering Services</td>
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Fuel cells continue to be the subject of research as an alternative propulsion source to the internal combustion engine. The appeal of using fuel cells is that a higher energy efficiency can be achieved.

Efforts to commercialize fuel cells are continuing, but there are challenges to overcome. In a previous TLT article, modifications to a fuel cell containing a proton exchange membrane based on copolymers of perfluorosulfonic acid and perfluoropropylene were described.1 The researchers dispersed tungsten carbide nanoparticles in the copolymer matrix, which served to improve fuel cell durability and reduce cost. The latter was due to the tungsten carbide replacing platinum.

A solid oxide fuel cell uses a solid oxide electrolyte and ceramic or ceramic-metal composite electrodes. The key reaction taking place at the cathode is the reduction of oxygen gas from the air to the oxygen anion, $O_2^-$. Meilin Liu, Regents’ Professor in Georgia Tech’s School of Material Science and Engineering in Atlanta, says, “This process, known as the oxygen reduction reaction, involves several distinct steps. Initially molecular oxygen adsorbs on the surface of the cathode followed by dissociation of oxygen molecules to monoatomic oxygen species through the use of transition metal oxide catalysts. Surface diffusion follows, moving the oxygen species to vacant sites in the catalyst where partial reduction takes place. Then the oxygen species jumps through the vacant site to the other end of the fuel cell to react with hydrogen and produce water.”

According to Liu, the state of the art cathode under evaluation is an oxide based on lanthanide, strontium, cobalt and iron that is known as LSCF. He says, “The LSCF cathode is very effective in the temperature range (600-800°C), but performance issues are present due to strontium segregation.”

Key Concepts
Strontium migration to the surface leads to the degradation of the LSCF cathode of a solid oxide fuel cell.

A multi-phase catalyst coating applied to the LSCF cathode reduced strontium migration and improved the rate of oxygen reduction in the fuel cell.

Under operating conditions of 600°C and a constant cell voltage of 0.7 V, degradation was observed with the uncoated LSCF cathode while no performance change was observed with the coated LSCF cathode after 250 hours of operation.
When the LSCF cathode of a solid oxide fuel cell is exposed to air containing carbon dioxide and moisture, strontium tends to migrate to the surface, leading to the formation of insulating phases that degrade the catalytic activity of the cathode. Liu says, “A noticeable reduction in solid oxide fuel cell performance is seen after thousands of hours of operation due to this degradation.”

To eliminate this problem and enable solid oxide fuel cells to operate at least over a five-year period, a new approach is needed to minimize cathode degradation. Such an approach has been developed.

**Multi-phase catalyst coating**

Liu, Dr. Yu Chen, postdoctoral research associate, and their colleagues modified LSCF through the preparation of a multi-phase catalyst coating that significantly increased the performance and durability of the cathode, leading to improved solid oxide fuel cell performance. Liu says, “We found that by applying a specific coating containing segregated nanoparticles consisting of oxides of barium and cobalt (BaCoO₃) and oxides of praseodymium and cobalt and a thin film containing oxides of praseodymium, barium, calcium and cobalt (PBCC), we significantly improved the rate of the oxygen reduction reaction and the durability of the cathode.”

The researchers designated this heterogeneous catalyst as a multi-phase catalyst coating. Liu says, “The coating exhibited a thickness of 10-20 nanometers, and the oxide nanoparticles were about 5-10 nanometers in diameter.”

A schematic of the multi-phase catalyst coating is shown in Figure 1. Microanalyses revealed the composition of the coating and showed that two types of nanoparticles were present within the coating.

Liu says, “The multi-phase catalyst coating enhanced the oxygen reduction reaction and acted to prevent strontium segregation even in the presence of carbon dioxide and water. The thickness of the coating is critical to ensure performance. Too thin of a coating could have limited durability, while too thick of a coating might result in reduced performance due to increased resistance to ion transport.”

Standard techniques were used to evaluate the electrochemical performance of the multi-phase catalyst coated LSCF cathode. Using a model cell, the researchers showed that the coated LSCF displayed a one order of magnitude reduction in polarization resistance compared to LSCF. Liu says, “Impedance spectroscopy showed that the cathode with the multi-phase catalyst coating showed greater tolerance to contaminants and smaller resistance to oxygen reduction.”

Durability testing was conducted by evaluating the coated and uncoated LSCF cathode at 600°C under a constant cell voltage of 0.7 V. Performance degradation was observed with the uncoated LSCF cathode after 250 hours of operation. But the cathode with the multi-phase catalyst coating showed no change in performance.

The researchers intend to optimize the performance of the multi-phase catalyst coating in the future and also develop a similar strategy to upgrade anode performance. Liu says, “The LSCF cathode is not yet suitable for use in automobile fuel cells because it is not effective at a lower operating temperature of 500°C. We believe that, as new materials are developed, the fuel cell has potential for automotive applications because it exhibits a greater energy density than batteries. Ultimately the best solution for plug-in electric vehicles might be a combination of the fuel cell and the battery.”

Additional information can be found in a recent article or by contacting Liu at meilin.liu@mse.gatech.edu.

**REFERENCES**

The move toward using battery technology in applications such as automobiles has focused on ways to improve the performance of high-energy lithium types. As this column has noted, flammability and toxicity continue to be major safety issues when working with lithium-ion batteries.

In a previous TLT article, researchers reported the development of a new cathodic material based on lithium, iron and oxygen that theoretically double the energy density of the battery compared to the material currently used, lithium cobalt oxide. The researchers determined that the new cathodic material was formed irreversibly from a related lithium iron oxide.

One approach that may assist researchers in determining the potential concerns about using lithium-ion batteries is to find out what reactions occur within the battery on the nanoscale in three dimensions. Jordi Cabana, associate professor of chemistry at the University of Illinois at Chicago, says, “Two well-known analytical techniques are available to evaluate reactions at the nanoscale. X-ray imaging methods prove effective in evaluating chemical reactions in bulk media but are limited due to their inability to resolve materials with diameters less than 30 nanometers. Electron-based imaging techniques exhibit atomic scale resolution, but they are limited in not being able to resolve materials that are thicker than 100 nanometers.”

The other problem is both techniques often do not provide an analysis of materials in two dimensions to differentiate a surface and inner processes. Cabana says, “This factor is particularly important because battery electrodes are clearly heterogeneous mixtures, and the active materials change internally in a heterogeneous manner.”

A new approach is needed to accurately evaluate how particles moving through a lithium-ion battery are engaged in redox processes in three dimensions. Such a process has now been developed.

KEY CONCEPTS

A new analytical technique, X-ray ptychographic tomography, was used to resolve how nanoparticles undergo redox reactions in a lithium-ion battery.

Heterogeneous particles were identified that are undergoing redox reactions at different rates.

This technique should be useful in understanding what makes a good battery electrode and troubleshooting battery failures in the future.

Three-dimensional analysis was conducted to better understand how redox reactions are occurring in a lithium-ion battery.

Factors affecting the rate of reaction include the physical orientation of the battery.
X-ray ptychographic tomography

Cabana and his research group, in collaboration with colleagues at the Lawrence Berkeley National Laboratory, devised an analytical technique known as X-ray ptychographic tomography to resolve nanoparticles undergoing redox reactions in a battery down at a resolution of approximately 11 nanometers. He says, “In X-ray ptychographic tomography, a coherent, nanoscale beam of X-rays is generated by the high-flux synchrotron accelerator at Lawrence Berkeley National Laboratory’s Advanced Light Source. The beam can be moved a few nanometers at a time, followed by sample rotation, to produce three-dimensional chemical maps of the nanoparticles involved in redox reactions.”

The researchers evaluated lithium iron phosphate as the cathode in this study. Nanoplates of lithium iron phosphate were prepared through reaction of phosphoric acid with lithium hydroxide monohydrate and ferric sulfate heptahydrate at 180°C for 10 hours. The nanoplates were then carbon coated with 20 weight percent sucrose followed by carbonizing at 650°C for three hours in an argon atmosphere.

Cabana says, “Lithium iron phosphate is a well-known cathodic material that has been used in batteries for some time. Once we prepared this material, our approach was to extract it from a lithium metal half-cell that had been 50% delithiated and use X-ray ptychographic tomography to examine the particles in a half-charged battery.”

The researchers evaluated 83 individual nanoparticles harvested from this electrode in a recent paper. To minimize error and enhance resolution, the particles were organized into three categories: greater than 70% alpha lithium iron phosphate (rich in ferrous ions), greater than 70% beta lithium iron phosphate (rich in ferric ions) and a 30%-70% mixture of both compounds.

Cabana says, “In the discharge reaction, ferrous ions are converted to ferric ions. But the process does not progress in a uniform manner. Rather, we detected heterogeneous particles (as shown in a three-dimensional chemical map in Figure 2) that contain percentages of all chemical categories. This process can be considered analogous to ice melting to form water. Ice does not completely convert to water at the melting point all at once but gradually with both solid and liquid phases present.”

One other point made by Cabana has to do with heterogeneity. He says, “The more heterogeneity seen in battery materials, the greater chance that battery instability can be induced through inadvertent overcharging/discharging.”

Cabana believes that the data shows the discharge reaction is not taking place at the same reaction rate in the nanoparticles. He says, “Think of runners in a marathon when considering why particles are not reacting at the same rate. Some runners move faster than others. Factors affecting the rate of reaction include the physical orientation of the battery. One consideration is that lithium ions and electrons involved in the redox reaction are not occupying the same space and not moving at the same rate. Their ability to diffuse has a direct impact on the rate of reaction.”

The researchers have developed a tool to study battery reactions, which should provide a technique for helping to understand what makes a good battery electrode and troubleshoot battery failures in the future. Cabana says, “We intend to examine the performance of the currently used layered oxide cathodic materials by combining lithium with various metals such as nickel, manganese and cobalt.”

Additional information can be found in the recently published paper and by contacting Cabana at jcabana@uic.edu.

REFERENCES


Switchgrass: Potentially more sustainable source of biofuel

This perennial species of grass is well adapted to the climate and the landscape but not linked to the food chain.

The use of corn as a feedstock for producing the biofuel-ethanol has presented problems due to its linkage to the food supply. Efforts to find an alternative biomass feedstock have focused on cellulosic biomass that is not used in food manufacturing.

One viable feedstock is switchgrass. Dr. John L. Field, research scientist, Natural Resource Ecology Laboratory at Colorado State University in Fort Collins, Colo., says, “Switchgrass is a native perennial grass species that is found naturally throughout the central U.S. Switchgrass has been a focus in efforts to find a feedstock that is not linked to the food chain because it is well adapted to the climate and the landscape.”

In a previous TLT article, switchgrass and other biofeedstocks were converted to bio-oil in a process known as fast pyrolysis. Rapid heating at a rate of 1,000 C per second and a limited residence time in the reactor led to the pyrolysis occurring at 500 C. The resulting bio-oil is a complex mixture that can be used as a fuel in boiler applications.

Besides identifying a proper feedstock, there is a need to ensure that the environmental impact of producing it is minimal and will satisfy regulations such as the U.S. Renewable Fuel Standard. One aspect that needs to be considered is biogenic emissions, exchanges of greenhouse gases between an agricultural ecosystem and the atmosphere.

Field says, “A big issue is the organic carbon content present in the soil. Losing it as carbon dioxide leads to an increase in biogenic emissions and gaining it means that the Greenhouse Gas (GHG) footprint is reduced. Other factors that need to be considered include the amount of water and nitrogen fertilizer required. The latter is the source of nitrous oxide an even more potent GHG.”

The challenge in working with a crop such as switchgrass is to maximize crop yields while limiting biogenic emissions.
Field says, “The current U.S. Renewable Fuel Standard requires 56 grams of carbon dioxide equivalent (gCO$_2$) per mega-joule (MJ$^{-1}$) lifecycle emissions reduction compared to the 93 gCO$_2$ MJ$^{-1}$ emissions attributed to gasoline.”

Field continues, “Switchgrass has an important advantage as a biomass feedstock because it requires only small amounts of fertilizer and water to grow.”

To demonstrate the potential for using switchgrass as a feedstock, Field and his colleagues conducted a modeling study from a 30,000-foot view to simulate how targeted landscape design can produce high crop yields in combination with a reduction in biogenic emissions.

**Southwestern Kansas**

The researchers evaluated the potential for growing switchgrass in the area near a currently idle cellulosic biorefinery in the southwestern region of the U.S. state of Kansas. The study included not only the county where the biorefinery is located but also all adjacent counties that cover a total area of approximately 4 million acres.

Figure 3 shows an aerial view of one part of the study area.

Field says, “We took into consideration such engineering issues as supply chain emissions, the amount of diesel fuel used in growing the switchgrass and transporting it to the biorefinery. Ecological issues included where on the landscape switchgrass was grown, and the optimal amount of fertilizer required also were used in the study.”

The researchers used the DayCent ecosystem model that had been developed at Colorado State University several decades ago and widely used. This model estimated not only crop yield but also biogenic GHG emissions.

Switchgrass production was simulated on a variety of land types with different soil, clay, sand and silt content, including marginal lands such as those classified under the Conservation Reserve Program, which are considered to be environmentally sensitive. But growing switchgrass on these lands led to higher emissions footprints due to a reduced ability to store additional organic carbon in the soil.

The researchers found that optimizing to reduce GHG emissions led to the greater use of silty soils that have a greater capacity to store organic carbon and less use of fertilizer. Doing so could reduce the footprint of biofuel production by 22 gCO$_2$ MJ$^{-1}$. Field says, “We intend to more closely evaluate marginal agricultural land, which is on the edge of what is economically sustainable. This land type is often vulnerable to erosion and has lower crop yields. We believe that the use of a switchgrass, a perennial, will be advantageous because it will leave the soil less vulnerable to erosion.”

Additional information on the modeling analysis can be found in a recent article or by contacting Field at John.L.Field@colostate.edu.

**REFERENCES**


MARKET TRENDS

The evolving global bright stock market

KEY CONCEPTS

Bright stocks are classified into three categories: Group I, Group V and alternate.

The demand for Group I, the most-used base stock, is declining due to changing technical requirements, mainly in automotive engines.

Synthetics are potential bright stock alternatives but can have cost and technical issues.

As demand decreases, opportunities emerge for suppliers of alternate products.

By Anuj Kumar

Bright stock is a high-viscosity lubricant base stock manufactured from the asphaltic residue that remains when lighter fuels and lubricant components are distilled from crude oil. This article classifies bright stocks into three broad categories based on the technical properties of the final product and production schemes (see Table 1):

1. Conventional API Group I bright stocks. These are bright stocks produced from conventional API Group I refineries using paraffinic crude and having a propane deasphalting (PDA) unit.
### Table 1. Typical Specifications of Different Types of Bright Stocks *(Table courtesy of Kline & Co.)*

<table>
<thead>
<tr>
<th>Parameter</th>
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<td>(30.0)</td>
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<td>L 2.0</td>
<td>L 0.5</td>
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<td>95</td>
<td>92.8</td>
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</table>

*a*-These properties are specific to the product (HyGold L2000) produced via a naphthenic crude source by Ergon.  
*b*-These properties are specific to the Product 120BS produced by SK at its Group II plant in South Korea.  
*c*-These properties are specific to Group I bright stocks produced by PetroChina at Karamay, China.  
NA-Not available.

2. **Group V bright stocks.**  
   These high-viscosity base stocks are derived from a naphthenic feedstock but have a lower viscosity index, less than 80.

3. **Alternate bright stocks.**  
   This includes all bright stocks not covered in either of the above categories. However, the final product quality matches that of either Group I or Group II. Broadly there are two examples of bright stocks produced in this category:

   a. **Using paraffinic crude.** SK is the only refinery that produces bright stocks using a paraffinic crude source and a non-conventional bright stock production scheme. This product has API Group II characteristics.

   b. **Using naphthenic crude.** PetroChina produces bright stocks at its Karamay, China, refinery using a naphthenic crude source, but the product has properties like those of API Group II products. Ergon in the U.S. has upgraded its production process at its Vicksburg, Miss., refinery to produce bright stocks from a naphthenic crude source. The product has technical properties like that of API Group I products.

### Bright stock demand and supply

Conventional API Group I bright stocks are the most widely available bright stocks across the world as this production scheme remains well established. Group V bright stocks are associated with a few refineries that produce high-viscosity products. As there are only a few refineries producing naphthenic base stocks, the availability and consumption of this set of bright stocks mostly remains a regional phenomenon. This holds true for alternate bright stocks, which are currently produced only by a limited number of refineries. Kline estimates that the global bright stock consumption of all three types of bright stocks stands at around 2.7 million tonnes in 2017 *(see Figure 1).*

Historically conventional Group I bright stocks have been an inevitable casualty of the Group I capacity shutdowns and conversions. The demand for Group I base stocks, especially lighter grades, have been declining across the world due to changing technical requirements, mainly in automotive engines. Modern day automotive engine oils performance requirements cannot be met by Group I. Hence, they have been substituted by higher quality Group II/III and polyalphaolefins (PAO) base stocks. This phenomenon, earlier limited to the developed markets of North America and West Europe, is now observed in other markets in Asia-Pacific and other regions.

There also is an oversupply of lighter Group II and Group III base stocks, which increases substitution of lighter Group I grades even from applications such as hydraulic fluids where there is no such technical demand for Group II/Group III. As the competition to lighter Group I grades became fierce from Group II and Group III lighter grades, many Group I plants shut down during the past two decades. A number of these plants had bright stocks facilities that also shut down. Kline estimates that during the period from 1997-2017, about 1.3-1.4 million tonnes of bright stock capacity shut down.

Bright stocks are most often used in applications where lubrication is needed at high tempera-
Applications, is skewed toward oils, especially in heavy-duty application. As the demand for gear requirement of bright stock in SAE 80W-90 is about 25% of the blend, the share of bright stock in SAE 85W-140 is around 25%-30% of the blend, the share of bright stocks in SAE 85W-140 is quite high in the overall formulation. As the demand for gear oils, especially in heavy-duty applications, is skewed toward grade, however, SAE 50 is still the most-used grade of marine cylinder oil across the world. One major factor impacting the global marine industry is the International Maritime Organization’s guidelines mandating sulfur emissions from ships to be reduced to 0.5% m/m (or mass by mass), effective Jan. 1, 2020. At present, contribution of cylinder oils in the overall sulfur emission is small as compared to that from fuel. Hence, ship owners’ primary focus is toward using low-sulfur fuel and after-treatment devices.

The primary use of bright stocks in a grease formulation is to increase viscosity. The applications where greases are used do not have fluctuations in operating temperatures (i.e., the temperature profile in the application is relatively flat); hence, when greases are meant to be used in high temperatures they are blended with thickeners. Mechanical stability and adhesiveness (ability to maintain its consistency after shearing), which are critical properties for greases, are not achieved using bright stock in a formulation. Instead, these properties are dependent on thickeners and sometimes additives. Hence, the demand growth for bright stocks in greases is not proportional to the demand growth for greases.

Rubber process oils or rubber extender oils are used in rubber and rubber products manufacturing to improve the processing of rubber compounds and increase the bulk of the rubber to reduce its cost. They are classified as paraffinic, naphthenic and aromatic types, based on the composition of the base stock. Rubber extender oils are selected for their solvency properties and used in the manufacture of synthetic rubber and elastomers. Rubber and rubber extender oils are compounded with upward of 50% bright stock.

In terms of regional demands, Asia-Pacific is the largest contributor to the global bright stocks demand. While North America and Europe account for a larger share in the global finished lubricant demand, their contribution to global bright stock demand is relatively smaller as these markets have lower demand of monograde automotive engine oils.

Consumption of all three types of bright stocks stood at around 2.7 million tonnes in 2017.

Within automotive gear oils, SAE 80W-90 and SAE 85W-140 are the major grades that consume bright stock. While the requirement of bright stock in SAE 80W-90 is around 25%-30% of the blend, the share of bright stocks in SAE 85W-140 is quite high in the overall formulation. As the demand for gear oils, especially in heavy-duty applications, is skewed toward

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In 2017 the supply for bright stock marginally exceeded demand, resulting in a very small surplus on the overall level. However, the situation differs by regions. While Asia-Pacific, Africa and the Middle East have wide deficits, Europe and North America have surpluses that are exported to other regions. Kline forecasts the global demand for bright stocks to continue growing at a rate of 4% per year to reach 3.2 million tonnes by 2022.
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stocks will decline at a CAGR of 0.1%-0.2% over the period from 2017-2027. The trend of shutting down high-cost Group I plants will continue in the future, resulting in the decline in global bright stock capacity. Moreover, the bright stock production will be limited by lower operating rates of Group I refineries as they face a declining market. Hence, the decline in supply will be even sharper than the decline in demand, resulting in a deficit of around 250-300 kilotonnes by 2027.

**Substitute products**

Kline & Co. anticipates the bright stock deficit to be met with the help of various substitute products. An evaluation of several products such as polyisobutlenes (PIBs), high-viscosity polyalphaolefins (hi-vis PAOs) and polyalkylene glycols (PAGs) based on technical suitability, compatibility issues, prices, consumer behavior and availability of these products suggests that PIB would be a key beneficiary of the emerging bright stock deficit.

PIBs are available in a wide range of viscosities and have a very high viscosity index. Due to its high viscosity, PIBs often result in volume savings as one part of a PIB can replace around three to five parts of bright stocks. To adjust the final viscosity of the product, usually a 500 N oil is required. As PIBs do not produce smoke, they can be preferred in applications where smoke is an issue due to lubricant burning. On the other hand, PIBs have inferior solvency compared to conventional Group I bright stocks, which could limit their use in applications where additive solvency is desired. However, the lack of additive solvency can be addressed by introducing other blend components such as naphthenic oils or alkylates.

In terms of technical suitability, high-viscosity PAOs are the best fit to replace bright stocks. However, PAOs’ very high prices make them an unattractive alternative. The current prices of high-viscosity PAOs are almost three to four times that of bright stocks. For substitution of bright stocks happens by PAOs, it will primarily be driven by the need for synthetic lubricants for better performance (see Table 2).

PAGs are produced in a wide range of viscosities, have low pour points and resist varnish formation. However, conventional PAGs have a big disadvantage in that they have poor miscibility with oil-based fluids. Hence, the use of PAGs as co-base fluid with other base stocks is limited. Moreover, due to its high-solvency property, the additive technology for PAGs becomes completely different, thus warranting a complete reformulation. Therefore, PAGs will be able to address a very small fraction of the bright stock deficit.

### Table 2. Comparison of Various Substitute Products (Table courtesy of Kline & Co.)

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<th>PIB</th>
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<td>Availability</td>
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<td>Price</td>
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<tr>
<td>Technical suitability</td>
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<td>Volume savings</td>
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<tr>
<td>Overall substitutability</td>
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![Favorable](https://www.klinegroup.com) ![Moderate](https://www.klinegroup.com) ![Unfavorable](https://www.klinegroup.com)

Based on technical suitability, high-viscosity PAOs are the best fit to replace bright stocks.

**Conclusion**

The bright stock market faces its own challenges arising from changing demand patterns and limited supply. This shortfall in the supply of bright stocks has resulted in higher prices of bright stocks. It also has resulted in growth in supply of similar molecules (high-viscosity base stocks), which has helped bridge the deficit. Overall, the demand outlook for bright stock is negative for automotive engine oils, but demand is expected to remain firm from industrial oils.

Despite these challenging conditions, the market provides opportunities to several stakeholders. The market presents growth opportunities for producers of alternate products along with producers of alternate and Group V bright stock. Though there isn’t any news of a new alternate bright stock capacity now, any new such plan will ease the market. Some of the existing well-run plants also can add to the supply by debottlenecking their existing facilities.

Anuj Kumar is a project manager at Kline & Co. in the Energy practice. You can reach him at anuj.kumar@klinegroup.com. Kline is an international provider of world-class consulting services and high-quality market intelligence for industries including lubricants and chemicals. Learn more at www.klinegroup.com.
Chevron Oronite's PCFlex ADDvantage offers the value and flexibility that will help you meet the new API SN Plus supplemental standard. In addition to OLOA® 55516, OLOA® 55517 and OLOA® 55526, we have developed OLOA 55530 as an optimized product. When combined with a specialized booster, it provides for dexos1® Gen 2 performance while minimizing supply and manufacturing complexity. We also offer OLOA 55531 that includes a pour point depressant (PPD). To learn more about our flexible solutions for API SN Plus, please contact your local Oronite representative or visit www.oroniteaddsup.com.
Robin Olson
This Rexnord executive works with experts on the American Gear Manufacturers Association to develop methods to predict the effect of gear lubrication on life.

TLT: What is AGMA 925?

Olson: AGMA 925 is an AGMA information sheet that covers the Effect of Lubrication on Gear Surface Distress. That’s a big topic! There are a wide variety of lubricants available to the gear engineer, and the way they respond to the sliding and rolling contacts in a gear mesh makes the difference between healthy operation, marginal operation and no operation.

Specifically the document discusses gear lubricants, their viscometric behavior and film thickness considerations. It presents methods that can be used to calculate the risk of scuffing, calculate the impact of regimes of lubrication on macropitting and predict wear between gear teeth.

AGMA 925 discusses micropitting but doesn’t contain any methods that can be used to determine when micropitting between two gear teeth will start. The AGMA Helical Gear Rating Committee identified that this is an area of improvement for the document. In 2015 the committee started a subcommittee to review the document and develop a way to calculate micropitting risk. This project is well underway in the committee.

AGMA 925 is an information sheet, not an AGMA standard. As an information sheet, it serves as a general guideline and source of information about lubricants, their properties and their general tribological behavior in gear contacts. It was introduced as an aid to the gear manufacturing and user community and relies on the accumulation of feedback data for future enhancements and improvements. It is not meant to be used as criteria for contract acceptance. The document was last revised in 2003.

TLT: What role does lubricant selection have on gear application and life?

Olson: Lubricants create a film thickness that separates the gear tooth surfaces as they pass through mesh. Within a gear drive, it also prevents roller bearing surfaces from coming in contact and evacuates the heat that is generated within the bearing. The basic mechanical ratings for gear tooth strength and durability and bearing L10 life assume that the proper film thickness lubricant and application conditions affect the gear teeth in operation. Many of the users of the document refer to it when they suspect that scuffing or wear may be influential in the life of the gearing.

If the methods predict that there will be a problem with tooth surface distress, then the gear engineer must decide what to change to avoid the damage. This could be a change to the lubricant, a recommendation for application changes or a modification of the gear tooth geometry. This may require recalculation of mechanical capacity.

TLT: What is the role of AGMA 925 in designing a gear and setting an application envelope?

Olson: AGMA 925 is a companion document to the general rating standard, AGMA 2101-D04 (Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth) and its application standards. After a gear design is completed and the mechanical ratings are known, AGMA 925 can be used to determine whether the combination of loads, geometry
Given all of that, lubricant selection is critical in the successful performance of a gear drive in application. An incorrect selection can quickly lead to damage in the gear teeth or bearings or overheating in operation. When selecting the lubricant, it’s best to follow the recommendations of the gear drive supplier for lubricant type, viscosity and quantity. Preventive maintenance checks should be set up to regularly test the oil for oxidation. Ideally this would be done through onboard monitoring of the oil as we’ve seen in the new IIoT offerings for gear drives. If regular testing and monitoring is not possible, plan to regularly change the oil. This will ensure that the gear drive has the best chance for a long life.

**TLT: Do you see advancements in the lubrication and gear fields that will get worked into an update of the standard?**

**Olson:** Two main advancements are in the development of lubricants and surface finish techniques.

In lubricants, synthetic base stocks with additive packages that enhance performance or accommodate severe operating conditions have become increasingly available. They typically have flatter viscosity indices, which means that they retain viscosity over a wider variety of temperatures than a mineral oil will. This results in less oil changes and longer lubricant life. Each type of synthetic lubricant has unique properties and all have limitations such as compatibility with other lubricants, seals, backstoppers, paints, filters and plastics.

The use of failure load stage to classify the scuffing or micropitting resistance of a lubricant also is becoming a familiar parameter in lubricant specifications. This value indicates how well the lubricant performed on an FZG test rig per an ISO- or FVA-specified test. It doesn’t necessarily include the performance of a specific gear set in a particular application, but it does provide a relative comparison for performance between lubricants.

The update of AGMA 925 will contain new sections to cover lubrication, elastohydrodynamic lubrication (EHL) regions in the zone of contact, FZG testing and selection of lubricants. The AGMA 925 committee also is reviewing advancements in the measurements of tooth flank roughness. When the original testing for scuffing and wear was completed back in the 1950s and 1960s, surface finish measurements were fairly basic and depended on the measuring tool and the filters that were applied. Today the measuring tools can work in several different measurement methods with varying filter levels. It’s important that the measurements are taken in the correct direction along the tooth surface. In addition, we are reviewing the inclusion of waviness in the roughness measurement to determine when asperity contacts are significant in the life of the gear set. The AGMA 925 update will contain definitions of the various roughness methods as well as discussion of how to use filters in measurement and dimension and tolerancing symbols on drawings.

**TLT: What changes do you anticipate pursuing in relation to the standard?**

**Olson:** The primary reason for opening a project with AGMA 925 is to add a calculation method for the risk of micropitting. Micropitting has been mentioned in the document for some time but with only a description of its appearance and no method to predict it. With the development of ISO 15144-1 (Calculation of Micropitting Load Capacity of Cylindrical Spur and Helical Gears), specification societies and end-users have expressed an interest in predicting the onset of micropitting. Unlike ISO 15144-1, which is based on film thickness limits, AGMA is working to develop a method based on asperity fatigue limits.

The AGMA 925 committee also is adding sections to the document that clarify and explain the aspects of EHL, FZG testing, surface roughness specification and measurements and lubricant selection. Our goal is to create a document containing:

- General methods that can be used to predict surface distress
- Helpful information about the influences on surface distress

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**Figure 1. Micropitting on misaligned carburized gear. (Figure courtesy of American Gear Manufacturers Association - ANSI/AGMA 1010-F14, Appearance of Gear Teeth - Terminology of Wear and Failure.)**
TLT: What is the difference between micropitting and scuffing?

Olson: Micropitting and scuffing are two different damage modes on gear tooth flanks. Micropitting is a Hertzian fatigue mode in which asperities on the surface of the tooth deform under cyclic Hertzian stresses and experience plastic flow. After a period of incubation, micropits begin to form. The region of micropitting appears dull, etched or stained with patches of grey. Micropitting can continue to grow, jeopardizing the tooth surface and leading to macropitting. It also can arrest as the asperities flatten out and stop contacting each other. Micropitting typically develops in the region of highest negative sliding along the line of action between the pinion and gear (see Figure 1 on Page 35).

Scuffing is a much more severe adhesion that is not a fatigue mode. It occurs when tooth surfaces come in contact, causing transfer of metal from one surface to the other. Typically this is caused by frictional heating due to high sliding velocity and surface pressure. Scuffed areas of the tooth have a rough texture and will appear as bands oriented in the direction of sliding. Because scuffing is not a fatigue phenomenon, the damage from scuffing appears quickly in the life of the gearing and typically progresses to failure (see Figure 2).

You can reach Robin Olson at Robin.Olson@rexnord.com.

Figure 2. Mild scuffing. (Figure courtesy of American Gear Manufacturers Association - ANSI/AGMA 1010-F14, Appearance of Gear Teeth - Terminology of Wear and Failure.)
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Arthur Drossel
Kenneth Foley
Adam Ford

Molly Hoff
Newton Hopkins
Scott Howard
Pericles Jimenez
G. Wayne Johnson
Lum Kai
Jawad Khan
Randy Kirby
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Jawad Khan
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Rational Rationality, Redux

Congress is considering action to reverse the effects of the Renewal Fuel Standard.

By Dr. Robert M. Gresham
Contributing Editor

You may recall that I went on a rant in the April TLT about how policy makers often do not consider the whole picture when writing laws or regulations, especially when technical matters are involved. Indeed, these lawmakers likely earned Ds and Fs in science classes, assuming they even took any science classes.

This is not to say their intentions are not good and often spurred by public sentiment, but the conception and execution often are flawed. The example I used was the Renewal Fuel Standard (RFS) as it pertained to the mandated use of biodiesel. In this case, these mandates led to forced use of a more expensive material that amounts to an indirect tax for U.S. citizens. Not only did the RFS not substantially reduce CO₂ emissions, it increased deforestation in Argentina (while generating more CO₂). Argentina reduced soy oil prices for countries other than the U.S., which amounted to price dumping.

Additionally, the RFS has mandates for use of ethanol in gasoline. Ethanol is grown from corn and mixed into gasoline, again as required by the RFS. However, gasoline companies would likely blend in some ethanol anyway (regardless of whether their product was bio or petroleum based) because it adds value as a fuel additive. We are required by law to grow corn and soy beans for the two biofuels per the RFS. This is great for Midwest farmers (think money and votes), but it is a waste of soil nutrients that could be used to feed the global population.

As we know from STLE’s 2017 Emerging Trends Report (available for free at www.stle.org), there is a rapid global increase in demand, primarily from emerging nations, for food, goods, services and, of course, energy. This increase necessitates rational thinking to provide for the growing needs of these nations, as well as our own. The real goal is to improve efficiency and productivity as economically and sustainably as possible, while managing emissions.

Eventually the RFS diverted 40% of the U.S. corn crop away from the food supply.

Well, as much as I would like to think someone read my rant and took action, independently of my article there does seem to be a growing movement to, in some way, phase out the RFS. According to a recent article in the Wall Street Journal by Thomas Landstreet, founder of Standard Research and partner of N3L Capital Management, “Even ex-Rep. Henry Waxman of California, a key sponsor of the original legislation establishing the standard, said Thursday [March 8, 2018], that he favors phasing out the mandate.” Landstreet further notes that growing bipartisan support in Congress has led to the discussion of a Greener Fuels Act.

Historically, the mandates began with the Energy Policy Act of 2005, which were expanded by the Energy Independence and Security Act of 2007. This expanded the program by providing generous tax credits and subsidies for growers and blenders. It also established ambitious targets, increasing annually, for biofuels.

Eventually this diverted 40% of the U.S. corn crop away from the food supply. This in turn led to harmful responses from the farming industry. Corn prices have historically floated around $2 per
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bushel; they rose in 2012 to $8 per bushel. Thus, farmers planted 17 million new acres with corn at the expense of soybeans, hay, wheat and cotton, thus driving those prices up as well. This resulted in livestock farmers culling herds due to the high cost of animal feeds, which again led to beef prices rising 60% from 2007-2012. Thus, the EPA froze the annual blend mandate, causing the bubble to burst.

Landstreet notes, “The country has endured a startling amount of economic disruption for what is clearly an inferior source of energy. Ethanol produces 34% less energy per volume than conventional gasoline, reducing cars’ fuel economy. As for its effect on the environment, a 2010 Congressional Budget Office study found that corn-based ethanol subsidies are terribly inefficient, with the government spending an estimated $754 per metric ton of avoided emissions—an astronomically high price tag compared with other policies. (The economics of climate change literature estimates the ‘social cost of carbon’ at far lower levels, meaning the program is inefficient even on its own terms.)”

Landstreet adds: “A 2008 study in Science found that converting natural environments for biofuel production can produce hundreds of times more carbon emissions than the biofuels themselves would save. No wonder ethanol mandates are losing support among environmentalists.”

Some of the early rationales were that the RFS would help with our energy independency. But now, with the deregulation of the shale oil industry, the U.S. is nearly energy independent. As previously said, I have been critical of many of our efforts in the name of renewable, sustainable energy, food, emissions, etc.—initiatives, which, when you peel back the layers, often involve politics, greed, bad science, ill thought-out subsidies or tariffs and the like. Yet we continue to emit ever more CO2 while continuing to tax U.S. folks with the latest energy fads that don’t seem to have much or any economic benefit or true efficacy.

Let’s hope Congress can, with a little rational thinking, correct some of this with the Greener Fuels Act under discussion. Again, we really do need a little rational rationality.

Bob Gresham is STLE’s director of professional development. You can reach him at rgresham@stle.org.

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Also referred to as computer-aided modeling, numerical modeling is using mathematical descriptions to provide predictions without the need of experiments. It usually employs high-power computing resources.

Numerical modeling has many advantages: It provides insight into why something happens by capturing complicated mechanisms, can be less expensive than experiments and sometimes produces results faster than experiments. Among the disadvantages of numerical modeling: Predictions can be wrong, results might be interpreted incorrectly, and it might not solve the issues at hand. Also, tribological interfaces can be an important factor that needs
to be included in all these applications, and most commercial software has no methodology for considering these effects.

Among the common applications of numerical modeling are:

- Gears
- Ball bearings
- Hydrodynamic bearings
- Electrical connectors
- Electronics heat sinks
- MEMS switches
- MEMS contacts
- Tire-road interactions
- Railroad wheels
- Hard drive read/write heads (bearings)
- Fasteners (nuts and bolts) (see Figure 1).

2. Molecular models. These applications are on a much smaller scale and are used for nanoscale solids, fluids and heat transfer. They are inherently multi-physical (most fields are considered). For molecular dynamics, each atom or molecule is considered as a particle governed by defined interaction forces between them. They can require extensive computational resources.

3. Intermediate models. These are hybrids—a continuum model that is linked to a molecular model—with some sacrifices. Lattice Boltzmann is an example.

In some circumstances, any of these applications can result in the wrong answer. Problems can include:

- Bad input
- Invalid boundary conditions or assumptions
- Multiple solutions
- Never converges (diverges)
- Coding errors or bugs
- Mesh convergence not satisfied.

Figure 1. Bearing rendering. (Figure courtesy of Auburn University.)
When using methods such as finite elements, the problem needs to be divided into small parts with enough elements. The number of elements or nodes should be doubled until the error of the desired quantity between cases drops below the desired accuracy.

**The tribology factor**
The big problem with numerical modeling in tribology is scale. Things on a very small scale affect things on a very large scale. When using numerical methods for investigating problems involving tribological interactions, additional difficulties arise:

- **Thin film lubrication.** Most commercial fluid dynamics are not suited for cases that have large dimensions in two directions and micro or nanometer dimensions across the film.
- **Roughness.** Factoring in solid surface contact and lubricant flow.
- **Surface chemistry or properties.** The effective properties or molecular models.

**The Reynolds Equation**
The Reynolds Equation is used to predict fluid behavior in thin films. It is a simplified fluid dynamics equation that can be solved using finite elements or finite difference methods and is usually used to predict fluid pressure (load-carrying capacity) as a function of geometry and sliding speed. Unfortunately it is not available in most commercial software.

For smooth surfaces with film thicknesses that are large compared to the roughness, the Reynolds Equation can be solved relatively easily. A function predicting the viscosity can be fit to measured data and used to calculate viscosity at each node as a function of shear rate, pressure and temperature.

**Molecular dynamics**
Molecular dynamics can be used to predict many phenomena, including the impact of additives that minimize the change of fluid viscosity with temperature. This application is able to predict viscosity index additive performance using molecular dynamics modeling. In the future researchers will be able to predict more and reduce testing requirements. Currently all the molecules in a real bearing can’t be modeled since it would be too complicated and expensive.

The molecular dynamics simulation method can be used to explore the possible effect of nanoparticles on thin film lubrication. For example, a similar system of silver nanoparticles in dodecane between iron walls was modeled. The system was sheared until the steady state was reached. The coefficient of friction for different cases was calculated, and the results suggest that nanoparticles affect the thin film lubrication systems and reduce friction.

**Surface roughness**
Roughness is a big issue in tribological modeling. With a very thin film, the roughness affects the film because the lubricant has to go around the asperities (see Figure 2). Roughness can be ignored in the full-film regime but must be considered in mixed and boundary lubrication.

Deterministically measured roughness and all detail when solving Reynolds Equation can be considered. It can be done, but it is computationally expensive. The Stochastic flow factor approach adjusts the average flow between the surfaces due to the roughness obstructions.

A modified Reynolds Equation was formulated to include asperity flow effects between two three-dimensional surfaces. These flow effects were taken into account in the form of flow factors, which were incorporated into a modified form of the Reynolds Equation.

\[
\frac{\partial}{\partial x} \left( \phi \frac{h^3}{12 \mu \phi_x} \right) + \frac{\partial}{\partial y} \left( \phi \frac{h^3}{12 \mu \phi_y} \right) = \frac{U_1 - U_2}{2} \phi_x \frac{\partial \phi}{\partial x} - \frac{U_1 - U_2}{2} \phi_y \frac{\partial \phi}{\partial t} + \frac{U_1 - U_2}{2} \phi_x \frac{\partial \phi_y}{\partial x} - \frac{U_1 - U_2}{2} \phi_x \frac{\partial \phi_y}{\partial t}
\]

The modeling of surface asperities on the microscale is of great interest to those involved in the mechanics of surface contact, friction and wear. When considering the area of contact between real objects, the roughness of their surfaces must be accounted for because it will determine the real area of contact between them. This real area of contact is approximately proportional to the friction. Since surfaces are rough, only the peaks or asperities come into contact. This interaction must be considered when studying the fundamentals of friction, wear and contact resistance.

There are many different scales of roughness and many different methods to model rough surface contact.

- **Hardness model.** The contact area is simply the force divided by the hardness (2.8-3 x yield strength).
- **Statistical.** The model surface as a statistical distribution of asperities with various heights and properties. It is computationally inexpensive.
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**Deterministic.** The real features of the surface are modeled with as much detail as possible. It is computationally expensive and there is no mesh convergence.

**FFT methods.** The problem is solved in frequency domain.

**Fractal.** Multiple scale roughness is considered. However, it assumes that surfaces are self-affine and often oversimplifies the contact mechanics.

**Multiscale.** Considers the multiple scales but without relying on fractal mathematics.

**Surface asperities**

Most of the previous works on the contact between rough surfaces employed cylindrical or spherical/ellipsoidal shape for the asperities. However, there are some works that employed sinusoidal asperities (see Figure 3). There is a wide variety of options to consider other effects such as elastic, elastic-perfectly plastic, strain hardening, sliding, adhesion and scale-dependent properties.4

For scale-dependent mechanical material properties, as the scale becomes smaller and there are fewer features in the contact area, scale-dependent features become relatively larger and the effective hardness (yield strength) of material increases.

**Molecular scale modeling**

For the molecular scale, continuum-based models appear to work for surprisingly small scales. Scale-dependent properties allow for continuum-based models to be adapted. However, some effects or phenomena seen in molecular scale modeling may be lost in continuum-based modeling. To predict the fundamental surface interactions that cause friction, a model of sliding spherical copper asperities and many other materials has been analyzed many times. Some cases take weeks to run. In order to verify the effectiveness of molecular dynamics simulations, recent works are being made to extend molecular dynamics capabilities into the same range as experiments.5

Many rough surface contact models have been implemented, including statistical, fractal and deterministic models. Graphic comparison of models shows that contact area increases with load. For modeling tribological interactions, these models can predict the contact pressure as a function of the surface separation.

Deterministic models can include the actual rough surface geometry and other effects directly into a finite element modeling (FEM) code, although this is not practical. Other models can calculate average pressure as a function of surface separation. The average pressure on a contacting surface can then be calculated in FEM based on the surface separation. Similarly, the electrical and thermal contact resistance can be predicted. Solid friction and wear also can be approximately predicted by assuming they are proportional or related to the contact area.

**Coupled solid and fluid problems**

Realistic tribological components can be modeled to consider both solid rough surface contact and the effects of fluid dynamics in a mixed lubrication model. FEM can be used to calculate deformations of components due to contact pressures, fluid pressures and thermal expansion.6 The described methods are coupled through their boundary conditions and so must be satisfied simultaneously. The Newton-Raphson method is often used to solve the non-linear problem.

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**Figure 3.** Sinusoidal asperity. (Figure courtesy of Auburn University.)

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**Auburn University tribology minor and research**

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- For information about Auburn University's tribology minor, visit http://eng.auburn.edu/programs/tribology/.
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The viscosity of lubricants depends on pressure. In heavily loaded contacts the pressure-dependent viscosity change can be significant. Under high pressure, lubricants can act as a semi-solid (very thick fluid). This might result in elastic deformation of surfaces in contact. This problem is solved by coupling elastic deformations of the surface to the fluid pressure predicted by Reynolds Equation. This is commonly known as elastohydrodynamic lubrication and is usually solved numerically.

**Compressible squeeze film bearing model**

Researchers at Auburn University wanted to take a solid surface and vibrate it so that there is no sliding, and lift can actually be generated between the surfaces just by vibrating (see Auburn University Tribology Minor and Research). They wanted to find out what frequencies and amplitudes were required to levitate the top surface and create a squeeze film effect. The resulting squeeze film bearing model, which included roughness and lubrication, yielded the following results (see Figure 4):

- Hydrodynamic lift occurs due to a relative normal motion between two parallel surfaces separated by air.
- Alternate compression and decompression produces a steady state film pressure.

**Conclusions**

Computer-aided modeling capabilities are very strong for general components. The introduction of tribological aspects into a model tends to introduce complications that are often neglected by commercial software. There are some specialized packages out there, but they are hard to find. Care must be taken when using numerical methods as erroneous predictions can result.

Thin film lubrication is effectively modeled using Reynolds Equation and flow factors. It is important to include the effect of micro and nanoscale roughness between the surfaces of much larger components. Although it is still an evolving field, current models are able to make complex predictions of tribological components. Researchers have just scratched the surface.

Jeanna Van Rensselar heads her own communication/public relations firm, Smart PR Communications, in Naperville, Ill. You can reach her at jeanna@smartprcommunications.com.

**REFERENCES**

6. This paper has a good example of this: Jackson, R.L. and Green, I. (2008), “The thermoelastic behavior of thrust washer bearings considering mixed lubrication, asperity contact, and thermostatic effects,” *Tribology Transactions*, 51 (1), pp. 19-32.
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The body mechanical

Inserting artificial joints into a biological environment can ignite the body’s ability to heal itself.

By Dr. Nancy McGuire
Contributing Editor

**Back in the 1970s**, the Bionic Woman’s medical implants gave her superhuman powers. People in the real world also had artificial implants, but these parts only restored some semblance of normal function to aging or injured bodies. Today medical implants still mainly repair and replace parts rather than enhance performance, but they come into play at a much earlier stage of damage, and their users typically enjoy a more active lifestyle than was previously possible.

Osteoarthritis, one major reason for joint replacements, is one of the 10 most common disabling diseases in developed countries. Worldwide, about 10% of men and 18% of women over age 60 show symptoms, and more than a million joints are replaced with artificial implants every year. Current estimates of the annual number of joint replacements in the U.S. put knees at 720,000, hips at 330,000 and temporomandibular joints (jaw hinges) at 3,000.

**A new landscape**
People have been getting hip implants on a mass scale since the late 1960s, says Jeremy Gilbert, Hansjörg Wyss Endowed Chair for Regenerative Medicine and professor of bioengineering at Clemson University in Clemson, S.C. Since then, surgeries have improved so drastically that they are now being used for a broader range of disease states, different stages of life and for very active people. Now people in their late 50s are getting hip implants, he says. Afterward they are still running and biking. Patient expectations are changing, he continues. People are less willing to just accept the pain—they want to fix the problem.

Gilbert notes that not only are implants being installed more often now, the kinds of operations now are more varied. Knee replacements are more common than hip replacements, he says, but people also are getting dental implants and replacements for various
parts of the spine and shoulder. That’s not even counting nonstructural parts, like stents, which have their own tribological issues (see Beyond Hips and Knees on Page 56).

Markus Wimmer, the Grainger director of the Rush Arthritis and Orthopedics Institute at the Rush University Medical Center in Chicago, also has seen a trend toward joint replacement at earlier ages, but he says this isn’t an ideal approach. “Total joint replacement is a cure, but you lose a [natural] joint. Early intervention could postpone the time when you have to replace the joint,” he says.

However, better joint replacements are a positive development in a less-than-ideal world. When Wimmer began his career in the 1990s, joint replacements would typically last 10–15 years. That was often sufficient for the older, less physically active patients who would get the implants. When people started living longer, more active lives, “we wanted to extend longevity” of the artificial joints, Wimmer says. “From an engineering perspective, we did a pretty good job,” he adds, explaining that we now have better materials and a better understanding of wear mechanisms, which can extend a joint replacement’s service life well into a second decade.

MORE THAN ONE MILLION JOINTS ARE REPLACED WITH ARTIFICIAL IMPLANTS EVERY YEAR.
Anatomy of a hip replacement

Hips, knees, shoulders, elbows, wrists—most of the joints in the body, in fact—are synovial joints. The ends of the adjacent bones are covered in tough, rubbery cartilage. Around the outside of the joint is a capsule made of strong, fibrous tissue, lined with a membrane that secretes viscous synovial fluid. Hip joints are a very sturdy type of ball-and-socket joint. The head of the femur bone forms a knob that fits into the hip socket on the lower part of the pelvis bone. The surrounding synovial capsule helps prevent an excessive range of motion that might dislocate the hip joint.

Artificial hip joint replacements have a ball attached to a metal stem using a modular junction that is designed to minimize vibration and other types of motion between the ball and stem (see Figure 1). The top end of a patient’s femur is surgically removed, and the stem assembly is anchored within the hollow center of the femur using a pressure-type cross fitting. Earlier types of hip implants fixed the stem to the bone using cement, but this setup was prone to microscopic movements of the stem within the bone, which promoted fretting and osteolysis (bone resorption). An artificial cup lines the hip socket to protect the bone from wear.

Various types of implants accommodate differences in weight and the intensity and type of physical activity among individual patients. The design is generally a tradeoff between biomechanical and tribological functions. Many athletes prefer hip implants with a larger femoral head ball that improves the joint’s stability and range of motion, but the larger contact area increases sliding distance and wear. Compare this with knee implants where better conformity between the articulating surfaces reduces contact stress but limits the range of motion and increases wear.

Synovial fluid: Nature’s lubricant

Artificial implants use the same lubricant that natural joints do: synovial fluid. Synovial fluid separates the bones in a joint, reducing wear on the cartilage. It also absorbs shocks and filters out debris and inflammatory substances while letting nutrients pass through.

The main constituent of synovial fluid is sodium hyaluronate (also known as mucin). This long-chain organic polysaccharide compound forms tangled, web-like masses that absorb large quantities of water. Hyaluronic acid or its sodium salt also is present in the vitreous body of the eye, the mucous membranes and the skin (see Figure 2).

Although research on the lubrication mechanisms of synovial fluid is ongoing, the consensus is that a combination of mechanisms interacts to provide lubrication. Two systems within a synovial joint require lubrication: the soft tissue system and the interface between the cartilage caps on the bone ends. The hyaluronate component of synovial fluid sticks to the sliding surfaces of the soft tissues and keeps them separated, providing boundary lubrication. (Because joints oscillate and change their direction of motion, a hydrodynamic lubrication wedge never has a chance to form.) Lubrication at the cartilage interface relies on glycoproteins in the synovial fluid. At low loads, the glycoprotein provides boundary lubrication. At higher loads, the lubricating film is a combination of synovial fluid and interstitial fluid that weeps from the cartilage itself. Here, the hyaluronate may enhance the longevity of the lubricating protein and act as a spreading factor.

People are less willing to just accept the pain—they want to fix the problem.

Mathew T. Mathew, Cedric W. Blazer Endowed Professor in biomedical science at the University of Illinois College of Medicine at Rockford’s Regen-
erative Medicine and Disability Research Lab in Rockford, Ill., notes that lubrication conditions right after joint replacement surgery might be very different from those under ideal conditions. Shortly after surgery, the joint area is bathed in a “pseudo-synovial” fluid, he says, because the synovial capsule has been opened and the joint has been exposed. The surgical wound may contain blood and tissue debris, as well as the synovial fluid, and it may take a long time to regenerate the normal environment, he adds.

**Implant materials**

Any joint replacement must restore ease and range of joint motion, attach securely to the bone, be compatible with the surrounding biological elements and offer a long service life. Very low wear rates are typical for today’s artificial joints; only about 4% of joints need replacing (for any reason) after seven years.1

Different joints present different problems, each requiring their own material solution. Hips, knees and shoulders involve large bones and large ranges of motion. Ankles, elbows, wrists and fingers have smaller motions, and spinal discs and temporomandibular joints must be capable of complex motions in three dimensions.

Until about 2009, hip implants had both the ball and the cup made from stainless steel or a corrosion-resistant cobalt-chromium alloy. However, this type of interface tended to wear and release debris and ions into the joint, sometimes causing adverse reactions.

Today’s implants use various combinations of metal, ceramic and polymer parts and coatings that minimize wear and extend the life of the implant. The most common hip implant configuration today uses a metal ball with a cup made from (or lined with) ultra-high molecular weight polyethylene (UHMWPE). An alumina ceramic ball with a polyethylene cup, or both components made from ceramic, also are somewhat common.2 There has been a recent resurgence of interest in metal-on-metal implants for younger, more active patients, but because these patients are more likely to have these implants for a longer period of time and put more wear and tear on them, the medical community is taking a cautious approach.3

Titanium alloys are good for spinal discs, but they require surface treatments to improve wear resistance. Joints where both contacting surfaces are made from zirconia-toughened alumina composite ceramics are becoming more popular, especially with younger patients, but these joints can squeak.2

Polyether-ether-ketone (PEEK) polymers are being investigated as longer-lasting replacements for UHMWPE. Carbon fiber-reinforced PEEK demonstrates good wear characteristics in simple geometry pin-on-plate studies and in total hip joint replacements. However, in low-conformity applications like knee joints, these polymers have wear rates that are significantly higher than for UHMWPE, and they have a tendency to delaminate and form surface cracks (see Figure 3).4

Gilbert notes that despite recent developments in materials science as a whole, the selection of alloys used in today’s joint replacements remains small. Titanium, cobalt-chromium alloy, stainless steel and nickel-titanium alloys all work well inside the body. Cobalt-chromium, now commonly used for hip replacements, was developed in the 1920s for use in dentistry, he notes.

The FDA started regulating medical devices and biomaterials in 1976, and pre-existing devices and materials were grandfathered in. New devices that can demonstrate “substantial equivalence to a predicate device” go through a much shorter FDA approval process than do devices that are completely new, Gilbert notes. “We can innovate a little bit,” he says, but designs typically don’t stray too far from what was available in the 1970s because of the high
investment and lengthy approval process needed to prepare a new device for market. New devices must be shown to be “safe and effective” (similar to the requirement for pharmaceutical products) rather than “substantially equivalent.”

New products that incorporate pharmaceuticals or stem cells into the device (combination products) must clear drug hurdles as well as device hurdles—a process that is “exponentially more difficult,” says Gilbert. The medical device field is shaped to a large degree by the regulatory process, he adds, but the process does catch harmful products before they get onto the market.

Patients can be reluctant to try new devices because of the risks associated with such an integral part of their daily lives. Issues with innovative devices can’t be tested easily, Wimmer says. Unlike new pharmaceutical products, which produce results almost immediately, joint replacement implants are meant to last for decades, and testing requires extended time periods, he adds, noting the need for better, more informative tests.

Unlike wear particles in a machine, micron-sized wear particles in a body not only cause friction, they can stimulate an immune response. Wimmer, who studies the macrophages that attack these foreign bodies, found that polyethylene particles produce a continuum of inflammatory responses.

Osteolysis is one such response; bone material breaks down and is reabsorbed by the body. The osteoclasts that normally digest proteins and minerals to assist in bone maintenance and repair can break down healthy bone tissue around a prosthesis, causing the device to loosen in its socket. The resulting abrasion causes both the bone and the implant to shed particles, causing even more inflammation.

Solutions to abrasion problems can work against solutions to fatigue problems caused by loading and vice versa. More highly cross-linked forms of polyethylene can reduce adhesive wear but are more brittle, Wimmer says. Cobalt-chromium is especially hard on polyethylene, requiring a highly cross-linked polymer or a vitamin E radical scavenger. It’s a matter of finding the optimal tradeoff between the competing factors, he says.

Corrosion mechanisms
The metal alloys used for joint implants are extremely corrosion-resistant in a laboratory environment. Inside the body, it can be a different story.

Fretting corrosion, which occurs as the result of minute vibrations in the contact area between two materials under load, is only recently receiving intensive study, partly as a result of the problems encountered with metal-on-metal hip joint replacements. Fretting occurs in the absence of lubrication, and it involves contact between surface asperities and movements on a scale of nanometers to millimeters. Oxidized debris particles are often harder than the bulk surface, and these particles can abrade the surface, accelerating the fretting process.

The interface between the ball-and-socket taper of a hip replacement joint can fret easily, says Wimmer. Cobalt-chromium resists abrasion and corrosion well under normal conditions, but the alloy degrades when both processes act in synergy. Even small quantities of debris and ions can cause inflammation, which is one of the reasons that metal-on-metal joints are under scrutiny, he says. The body responds to excessive amounts of metal degradation products by forming areas of inflammation and masses of necrotic tissue that look like tumors around the metal debris, he adds.

Switching to ceramics, which are more inert to corrosion, is one solution. There are better, more forgiving materials out there, says Wimmer, but the industry is reluctant to innovate because of regulatory issues.

Since metal-on-metal hip implants have fallen out of favor and been replaced with other materials, sliding corrosion of the head on the cup has been minimized, but micro-motions at the head-neck and neck-stem connections still sometimes result in fretting corrosion. Mathew’s student Dmitry Royhman found that variations in loading, micromotion amplitude and pH influence fretting corrosion at modular junctions. Another of his students, Maria Runa, studied fretting at the stem-bone junction and found more osteolysis than corrosion.

Tribocorrosion in a biological environment has recently emerged as another area warranting further attention. Tribocorrosion is a synergistic phenomenon—tribology accelerates corrosion and vice versa. “It’s more than just an additive effect,” Mathew says. For example, abrasion erodes the oxide surface from a titanium implant, exposing a fresh metal surface that oxidizes. The electrochemical repassivation process doesn’t always...
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balance out the mechanical de-passivation process, so repassivation can sometimes produce more erosion, releasing materials into the surrounding media. 

Mathew’s research group made a mechanical tribocorrosion hip simulator in 2009, and they found that rubbing increases corrosion by an order of magnitude (see Figure 4). Stress corrosion is a known phenomenon, but contributions from tribological processes within electromagnetic fields are still not clearly understood, he says.

Implant manufacturers and researchers perform tribotests to estimate the service life of their products, Mathew says, but it is difficult to simulate the complex biological joint environment. Sometimes implants that performed well in laboratory tests last only a matter of months inside the body. Inside the body, implants must contend with acute or chronic infections and the resulting immune response, various medications, chemicals from tobacco smoking, loading and stress from obesity and a range of other individualized factors, he says.

Gilbert’s group is investigating the role of inflammation on promoting corrosion. The body is a salt water environment, he says. Implants release particles and ions, which the body recognizes as foreign material. The response mechanisms haven’t been fully established, he says, but toxicity is one possibility. A typical immune response releases chemicals that might promote the release of more particles and ions from the implant, creating a feedback loop, he says.

Reactive oxygen species stand out as an area of interest, Gilbert says. Immune cells generate hydroxyl radicals, hydrogen peroxide, hypochlorous acid, peroxynitrites and superoxide anions. “There’s a whole mix of these oxidizing agents that go after foreign bodies,” he says. In the lab, when you put reactive oxygen species into salt water, it has a dramatic effect on alloy corrosion.

“The hypothesis that inflammatory species can alter the corrosion process is still pretty new,” he says, noting that his group is still in the early stages of modeling the processes. They search the literature to find which cells make specific reactive oxygen species and in what concentrations, and they make similar mixtures in the lab for use in corrosion testing and testing for passive oxide film formation. So far they have tested hydrogen peroxide and hypochlorous acid, and they found that both species enhanced corrosion.

Gilbert’s group also found that electrochemical reduction reactions produce hydroxide ions and reactive oxygen species that can promote corrosion. Bone cell cultures on titanium or cobalt-chromium substrates placed into a reducing environment can die off within a matter of hours. These reduction reactions haven’t been looked at much, Gilbert says. “How this happens inside the patient isn’t really understood,” he adds, but tribocorrosion may play a role. His group is investigating how electrical potentials arising from tribocorrosion of metal-on-metal contacts can kill cells, even outside the rubbing area.

During a study on fretting corrosion, Gilbert’s group used a potentiostat to control the electrical potential in a cell culture (see Figure 5). The cells lived until the potential crossed a threshold, showing that the electrical potential rather than the wear debris was killing them. “We’re not seeing this in patients yet,” he says.

**Figure 4. Hip implant simulator.** (Figure courtesy of Mathew T. Mathew.)

**Figure 5. MC3T3-E1 cell culture.** (Figure courtesy of Jeremy Gilbert. Image taken by Shiril Sivan, Ph.D.)
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adding that the conventional view focuses on wear particles and ions. These things do cause harm, but they aren’t the whole explanation, he says.

Bodies are more self-correcting than machines, Gilbert continues. The alloys we use for joint replacements also are used in saltwater environments like the oil platforms in the North Sea, where fretting is usually a minor annoyance. However, oil platforms don’t have immune systems or redox homeostasis mechanisms like the body does. The body tries to maintain a balance, Gilbert says. There are mechanisms for control and feedback, and when you get outside the range the body can handle, cells start to die.

**Wear measurements**

Unlike an engine or a gearbox, you can’t just shut down a human body to do maintenance or drain out all the synovial fluid and replace it with a test lubricant. Medical tribologists face distinctive limitations on observing part failures in progress and examining mechanical systems *in situ*. Many humans would object to being observed all day by a video camera or an engineer, or to carrying out their daily functions while feeding data to a laboratory instrument. By the time patients come to the hospital for an implant replacement, they are often in distress and in no mood to be interviewed and examined by anyone other than their physicians.

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**Wear testing methods**

Wear testing takes a variety of forms designed to assess surface topographies and wear progression for the complex shapes of teeth, knees and hip joints. Here are several methods currently in use.

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<tr>
<td>• scanning electron</td>
<td></td>
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<tr>
<td>Digital comparison of a test specimen with</td>
<td>• Works with specimens that cannot be</td>
<td>• Repeated measurements may be required to assess precision</td>
</tr>
<tr>
<td>a CAD model or 3D scan of an unworn specimen</td>
<td>assessed directly</td>
<td>• Matte coatings may be required for reflective or transparent specimens</td>
</tr>
<tr>
<td></td>
<td>• Assesses wear distributions with 5- to 10-micron accuracy</td>
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*Source: Ref. 11.*
Thus, medical engineers typically resort to using mechanical wear simulators during the process of getting joint replacements approved for clinical use. Various tribometric instruments have been adapted for use with joint implants and tissue cultures, with promising results (see Wear Testing Methods). Accelerated testing hasn’t proved feasible, however, because it doesn’t accurately represent clinical use. Computer simulations could help eventually, but the biomechanical environment around the joints hasn’t been fully characterized, and the degree and type coupling between interactions at the contacting surfaces and interactions at the musculoskeletal level isn’t well known.2

Laboratory tests must try to replicate conditions in the body as closely as possible, but it’s not a simple task. Take lubricants, for example. Artificial implants use the body’s own synovial fluid as a lubricant. A typical healthy knee joint will contain 1-2 mL synovial fluid, says Wimmer. Wear tests in the lab require 150-200 mL or more, so it’s hard to collect enough synovial fluid for lab testing. Also, it’s very expensive and it decomposes. The hyaluronic acid in synovial fluid gives it a high molecular weight and drives the viscosity properties, but also it’s very expensive.

Wimmer’s research group uses a surrogate material based on bovine serum, which consists mostly of albumin protein. Bovine serum is plentiful, economical, thoroughly studied and has ISO standard preparation methods. The protein content of Wimmer’s test fluid is similar to that of synovial fluid, but the rheology is different.

Wimmer’s group tested worn implant components, tissue samples and wear particles retrieved from live patients who were getting replacement implants, and they compared these to tissue samples and implant components that hadn’t failed, retrieved postmortem from other patients. Even though the rheology for bovine serum was different than for hyaluronic acid, the wear mechanisms were similar. He cautions, however, that, “you have to be careful about extrapolating results” from one implant material to another. Results of bovine serum tests with polyethylene don’t necessarily carry over to ceramics, metals or other combinations of materials, he says.

Mathew’s research group uses a tribocorrosion apparatus in an incubator to simulate in vivo conditions for tissue cultures. You can put a new material into a machine and it works well, Mathew says, but individual patient anatomies may produce different results. It’s difficult to set up models that replicate conditions within the body, so interactions among clinicians, biotechnologists and bioengineers are key to understanding the system.

Mathew’s group gets patient histories, symptoms and demographics along with the retrieved implants they study. They don’t typically interact directly with the patients, however, because of privacy concerns and the need for physicians to act quickly in an emergency situation.

Wimmer notes that the medical community feels that it has solved the problem of “total joint wear” (premature failure), and this failure is usually because of infection rather than tribology. Joints also fail because they weren’t installed correctly or the surrounding bone reorganizes, causing the prosthesis to become loose. Tribology research was an active area for the past 20 years, but the field has matured, he says, and the focus has shifted to lowering infection rates, which have stayed constant at about 1%-2% for many years.

Most of the tribological issues occur in knees, ankles and hips, says Wimmer. There aren’t as many tribological issues with shoulder joints, although some new research is looking into this area as well. Shoulder joints consist of several small bones rather than two large bones, and they have much more soft tissue, so finding a way to anchor a device to the bone is a more complicated problem. Also the range of motion is much greater for shoulders than it is for hips and knees (see Figure 6).

Figure 6. Shoulder replacement. (Figure courtesy of Wikimedia Commons. Author: Lucien Monfils.)

Hips, knees, shoulders, elbows, wrists—most of the joints in the body, in fact—are synovial joints.
biological environment. Much of today’s research focuses on integrating medical devices and biomaterials into a living system and harnessing the body’s own capabilities to help it restore itself.

Very few tissues in the body naturally regenerate, Gilbert says—wounds form scar tissues rather than regenerating healthy tissue. He cites research on regenerative methods—still in the early stages—that attempt to direct stem cells to regenerate bone cells. To do this successfully, he says, you need to develop substrates that act as scaffolding for the growing cells and drugs or other cues that prompt the cells to grow in a certain direction and control immune and inflammatory responses.

Tissue engineering, using the body’s own tissues to regrow natural parts, is in its infancy. Regenerated cartilage can be used to repair injuries, but it’s not used much now for osteoarthritic applications, says Wimmer.

Genetic engineering also is in its early stages. Wimmer cites one research group that uses knockout mice, which have one specific protein-making gene activated or deactivated. This group is looking at lubricin, a protein that is important in boundary lubrication at the cartilage surface. The proteoglycan 4 gene (PrG4), which encodes the instructions for making lubricin, could be an important target for treatment, Wimmer says.

Helping people take care of their own joints so they don’t need artificial replacements is another active area of research. A self-monitoring hip implant that could signal your cell phone and alert your doctor could catch problems in the early stages, Gilbert says. His group is currently working on ways to monitor implants for corrosion. Sensor development and intensive data analysis could provide solutions in the near term, while tissue engineering and regeneration technologies are coming up to speed, he says, but if devices are to provide useful feedback, you have to find out what signals are important.

Wimmer and his colleagues are currently working on shoes with pressure-detecting insoles that provide feedback to a patient’s smartphone. The aim is to teach people to walk differently in order to mitigate the effects of arthritis.

Medical imaging techniques could provide physicians with early warnings of impending joint failure. Noninvasive, in situ diagnostics like functional MRI scans or Raman spectroscopy could provide valuable information on chemical changes.
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processes as they happen, but we’re not there yet, says Wimmer. However, this type of investigation could bring the tribosystem into the lab, allowing researchers to watch healthy patients and those with arthritis as they perform various activities.

Just as oil analysis can warn of impending machine problems, developing tests for biomarkers could give an early warning for inflammation, infection and immune responses, says Mathew. His research group is working on a biosensor for metal ions and particles in the blood. “It’s like a glucometer but for metal,” he says. Particles from human joint implants have a lot of unknowns, he says. They aren’t just metal particles, and they can range in size from 10-200 nm. Metal particles and ions can form organometallic complexes with proteins, and nanoparticles can incorporate into cells, causing them to die.

Taking a pharmaceutical approach could be useful. Wimmer cites the example of today’s eye drops, which supplement or replace the lubricating fluids on the surface of the eye.

PREVENTING THE NEED FOR IMPLANTS ALTOGETHER REMAINS A PROMISING BUT ELUSIVE GOAL.

He notes that people currently get hyaluronic acid injections for their knees to reduce joint friction, but in reality the pain may decrease because hyaluronic acid scavenges radicals produced by inflammation.

Room for improvement Reducing implant infection rates is one area that is ripe for improvement, says Gilbert, adding that this rate has held steady at 1%-2% for the past 25-30 years. Gilbert is investigating ways to use electro-chemical potentials, which have proven so damaging to human cells, to kill bacterial biofilms on metal implant surfaces. “It’s a lemons-to-lemonade approach,” he says.

Preventing the need for implants altogether remains a promising but elusive goal. Most of the time by the time the patient comes in, the damage is already done. Wimmer asks, “How can we identify disease markers that could serve as an early warning?” We don’t have one single marker for osteoarthritis at present; there’s no clear signal for why certain people develop this and some don’t, he adds. “It’s very complicated in the body,” he says. Biology, chemistry, mechanics—“this all needs to come together.”

Gilbert notes that researchers spend their time studying what can go wrong with implants and trying to prevent or mitigate those problems. But overall only a small percentage of joint implants develops problems. “Implants provide tremendous benefits to millions of people,” he says. Still, problems must be addressed. Patients have high expectations, Gilbert says. “They need to understand these things are amazing but imperfect, and they still present a technical challenge.” Sometimes things happen even when you do everything right, he adds.

“You have to remember that you’re working for the people,” and keep a focus on the patient, Mathew says. The patient wants to know, “What’s going to happen to me?”

Nancy McGuire is a free-lance writer based in Silver Spring, Md. You can contact her at nmcguire@wordchemist.com.

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Correlating local microstructure to local tribocorrosion behavior

J. Michael Shockley*, Derek J. Horton¹, Kathryn J. Wahl²

1. Center for Corrosion Science and Technology (Code 6134)
   Naval Research Laboratory, Washington, DC 20375 USA
2. Tribology and Molecular Interfaces Section (Code 6176)
   Naval Research Laboratory, Washington, DC 20375 USA
* NRC Postdoc sited in Chemistry Division, Naval Research Laboratory, Washington, DC 20375 USA

Tribocorrosion, the synergistic interaction of mechanical wear and corrosion, can lead to extremely elevated surface degradation compared to either process alone. Most tribocorrosion literature has focused on the study of macro-scale tribocorrosion behavior where bulk material loss rates are measured and considered. However, some tribocorrosion behavior is localized, where complex microstructures may have particular phases more susceptible to tribocorrosion than others. One example is the secondary phases in 2507 super duplex stainless steel induced by heat treatment in the 600-900°C temperature range where chromium-depleted secondary austenite forms in fine lamellar structures next to the chromium-rich intermetallic sigma phase. By correlating local peaks and valleys in the corrosion current to the friction coefficient and local surface topography features, regions of higher and lower electrochemical activity were identified. This type of analysis promises to reveal precise details of wear-induced corrosion behavior.
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<tr>
<th>LUBRICITY &amp; EP ADDITIVES</th>
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<td></td>
<td>♦ Self emulsifying esters fit for high pressure machining of Aluminum, Magnesium, Titanium and Steel</td>
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<td>♦ Oil and water soluble: Stamping and Drawing lubricity agents</td>
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<td>♦ Phosphate Esters, Polyl and Polymeric Esters</td>
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<td>♦ PAG Esters and Block Copolymers</td>
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<tr>
<th>EMULSIFIERS</th>
<th>For Mineral Oils, Triglycerides, Esters and others</th>
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<td>♦ Nonionic and Anionic—Low foam, hard water stable</td>
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| RUST PREVENTIVES & CORROSION INHIBITORS | |
|-----------------------------------------| |
|                                         | ♦ Diacids blend |
|                                         | ♦ Self-Emulsifying rust preventives |
|                                         | ♦ Water soluble (Synthetic) rust preventives |
|                                         | ♦ Oil and solvent, water displacing rust preventives |

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Wear Analysis of Extracted Polyethylene Acetabular Cups Using a 3D Optical Scanner

Matúš Ranušák, Jiří Gallob, Martin Vrbka, Martin Hobza, David Paloušek, Ivan Křupka, and Martin Hartl

Faculty of Mechanical Engineering, Institute of Machine and Industrial Design, Brno University of Technology, Brno, Czech Republic; Department of Orthopaedics, University Hospital Olomouc, Faculty of Medicine and Dentistry, Palacky University, Olomouc, Czech Republic

ABSTRACT
Wear analysis of total hip replacements (THRs) is considered one of the most relevant research areas helping to improve the longevity and overall design of THRs. The coordinate machine method (CMM) and Fourier profilometry are the most common methods for measuring THR wear. This article presents optical scanner digitalization as a new method for measuring the wear of polyethylene (PE) acetabular cups. The aim of this article is to explore the potential of this method for the PE wear measurements. Optical scans for the purposes of this study were produced using an ATOS Triple Scan 3D optical scanner. The optical scanner is efficient and it can measure a large number of points for polygonization and for further development of the preworn models. In this study, the scanner first generated point clouds on a sample of 13 retrieved ultra-high-molecular-weight polyethylene (UHMWPE) acetabular cups. Next, volumetric models of the cups were created by polygonizing the point clouds. Reverse engineering was used to develop models of the original acetabular cups using the geometry of the unworn parts of the retrieved cups. A comparison of the two models then showed the total volume of the PE debris. The optical scanning method was validated against the gravimetric method using three new acetabular cups that were worn out on a hip pendulum simulator. Validation shows that the optical scanning method is a valid method for wear analysis of the retrieved UHMWPE acetabular cups.

KEYWORDS
Total hip replacement; polyethylene; wear measurement; optical digitalization; volumetric wear

EDITOR’S NOTE:
This month’s Feature article discusses the tribology of artificial joints, focusing on hip replacements and some of the hurdles in attempting to simulate real-life conditions for research purposes. The research presented in this month’s Editor’s Choice paper has the distinct benefit of performing wear measurements on retrieved acetabular cups. One significant hurdle for this research is overcoming the unknown starting weight of the cup; therefore any volumetric method for measuring wear must be based on extrapolated data. The main approach was to use surface geometry obtained by 3D optical scanning, and the results were shown to have decent correlation against the more time-consuming conventional methodology.

Evan Zabawski, CLS
Editor

INTRODUCTION
Total hip replacement (THR) is currently the most effective treatment of a number of hip afflictions that helps to alleviate pain and improve quality of life. This surgical procedure consists of removing the damaged joint surfaces and replacing them with artificial ones—an acetabular cup articulating with a femoral head on a femoral stem. The most common combination of bearing materials is a polyethylene (PE) acetabular cup articulating with a metal or ceramic head.

Along with a growing number of THRs, there is a growing need for revision surgeries due to prosthesis failure. Projected estimates made for the United States show that by 2030 the demand for primary THA will grow by 174% for primary surgery and 137% for revision surgery compared to the levels in 2005 (Kurtz, et al. (1)). By far, the main reason for a revision surgery is aseptic loosening followed by infection and dislocation. Aseptic loosening is causally associated with liberation of huge amount of prosthetic wear particles from the bearing surfaces. These particles stimulate the receptors of innate immunity to trigger a foreign body host response driven predominantly by macrophages and fibrocytes (Gallob, et al. (2)). That is why manufacturers and researchers are motivated to develop bearing materials with increased resistance to wear.

In order to measure the amount and rate of prosthetic wear, various in vivo and in vitro methods have been developed offering clinicians as well as researchers the ability to determine damage to the prosthetic cup liner (Patel,
et al. (3)). In vivo wear measurement methods rely on the assumption that a definite relationship exists between a quantifiable X-ray penetration of the prosthetic head in the cup and the true amount of wear. However, this article focuses only on in vitro methods. Gravimetric methods are suitable for evaluation of the cups tested under repetitive load cycle in special hip joint simulators when the pretest weight of a cup is known. The gravimetric method is also suitable for assessment of artificially worn components in experimental settings. The approach is defined by international standards ISO 14242 (Affatato, et al. (4)). The accuracy of this method is a minimum of 0.1 mg according to ISO 14242–2 (5).

However, this method is not useful for the analysis of extracted hip implants because the weight of the original cup in a preworn stage is not known. Therefore, development of alternative methods allowing the measurement of volumetric wear in a retrieved cup without knowledge of its weight before its use is needed (Bills, et al. (6)).

One of these methods is the analysis of surface geometry by a coordinate measurement machine (CMM). It is the most common method for measuring the geometry in manufacturing practice for control of the shape and dimensions of product elements. Use of this method has also become a correct standard method for the measurement of THR volumetric wear during in vitro tests (Bills, et al. (7); Martell, et al. (8)). A precise description of this method is clearly summarized in ISO 14242–2 (5), where a particular focus is dedicated to the maximum axial position error of measurement, which is described as $D = 4 + 4l \times 10^{-6}$ ($D =$ volumetric position error in micrometers, and $l =$ measuring length of the work envelope in millimeters). A location change of specimen must affect the volume by no more than 0.05%, and the point mesh spacing should be <1 mm. This standard offers a fundamental basis for the volumetric wear analysis with defined uncertainty of THR measurement (ISO 14242–2 (5)).

There are many studies describing the uncertainty and postprocessing algorithm related to this method. Kothari, et al. (9) published one of the first studies discussing the use of a CMM method to evaluate 22 retrieved THR components. Three hundred and twenty-five points were measured on the surface of a sample. The analysis was carried out in vitro and the examined implants were from metal material (Kothari, et al. (9)). The declared accuracy of this method was ±5 μm, with the definition described in geometrical product specification for CMM system declaration by ISO 10360–2 (10). Becker and Dirix (11) evaluated the precision of this method in the study comparing two CMM methods with a standard precision of 2.6 μm and a high precision of 1.2 μm. Lord, et al. (12) assessed metal-on-metal THR components, analyzing 32 femoral heads and 22 acetabular cups. The aim was to evaluate the effectiveness of the CMM method against a conventional gravimetric method. To determine the volumetric wear, a program using mathematical software was created. This program aimed to identify the origin of the spherical components from as wide an area of the articulating surface as possible. Then the worn area was localized.

Results of this study were verified by the gravimetric method. A validation procedure compared the mathematical and the gravimetric method. In Lord, et al. (12), three stages of mean absolute error—0.53, 0.50, and 0.24 mm$^3$—were reported for metal components. Another study examined distribution of the scan lines. The results dealt with the impact of the scanning method (polar, planar, etc.), distances between the scan lines, and distribution of points along a single scan line (Bills, et al. (6)).

An innovative surface analysis methodology is the optical method. A noncontact analysis provides simplification of measurements and postprocessing analysis. On the other hand, it offers new possibilities for postprocessing the scanned geometry. The main method used for complex analysis of THR geometry is based on reflectivity of the surface. Reflection of the incident beam is processed by an active or passive triangulation.

One of the studies focused on the use of a noncontact scanning method using Fourier profilometry (Rossler, et al. (13)). The study deals with a sinusoidal grating projector that creates an optical pattern on the object. This pattern is deformed by refraction on the surface, which is reflected in changes of its phase. The image is recorded by a digital camera. Information about the geometry and topographic depth is obtained by the image processing and by the mathematical algorithm computing the phase shift toward the reference plane. A relative percentage difference of this method compared to the gravimetric method is approximately 6.3% depending on the rate of volumetric wear (Rossler, et al. (13)).

Another approach, called scanning profilometry, uses only a one-strip projection. For the analysis of all surfaces, the object is rotated. The sensitivity and accuracy of this method depends on the size of the angle of object rotation. As a result, the whole profile is created by connecting the individual linear scans. The third coordinate is determined from the equal compared reference plane and the plane of refraction. The relative percentage difference of this method compared to the gravimetric method is about 10% (Pochmon, et al. (14)).

Zou, et al. (15) studied the macrostructure surface of acetabular cups. To establish an accurate method for digitizing a convex hemispherical shape, a laser probe fitted on a CMM machine is used. The principle of this optical method is based on triangulation. The surface was digitized at 0.1-mm intervals in $X$ and $Y$ directions divided into six scans. Then discrete points were merged into one surface data. Reproducibility of the method shows a volumetric difference of 1.411 mm$^3$ (Zou, et al. (15)).

Yun, et al. (16) used 3D optical scanning for validation of the reliability of a power point method to recognize volumetric wear in vivo from radiographs. This method is applied on 17 retrieved PE acetabular cups. A 3D laser scanner used for the analysis of the cup has a resolution of 2.0 megapixels and precision less than 0.01 mm. Data are postprocessed using special software (Geomagic, Morrisville, NC). The main mean wear volume achieved by the 3D laser scanning method is 1,146.72 ± 576.59 mm$^3$. The main message is to show that the power point method correlated well with the 3D scanning method (Yun, et al. (16)).

The aim of this article is to demonstrate the optical method...
as a method suitable for determination of volumetric wear and material loss. This method is applicable for retrieved PE acetabular cups at various stages of wear. The data obtained from the 3D digitizing process by the optical scanner are processed and evaluated using computer-aided design (CAD). Using a post-processing algorithm, it is possible to determine the amount of volumetric wear. A particular focus is given to validation of this method by the standard gravimetric method. This method ranks among the most innovative methods in the respective field to determine the volumetric wear of PE acetabular cups. Information on volumetric wear can be used to suggest an effective modification of geometry that would lower the friction and wear by effectively moving the lubrication regime away from the boundary regime toward the mixed and hydrodynamic lubrication regimes (Dougherty, et al. [17]; Choudhury, et al. [18]).

As indicated above, the CMM and the gravimetric method are the two most widely used methods for determining the volumetric wear on acetabular cups in vitro. These methods are very precise and have high confidence levels. In recent years, these methods have been supplemented with optical methods to obtain a more comprehensive and time-efficient analysis. The main advantage of the approach described in this article is its ability to reconstruct the unworn geometry of the cup. The analysis of geometry is made on the basis of a large number of points forming the point clouds. This advantage opens new opportunities for analytic and statistical approaches for determination of volumetric wear.

MATERIALS AND METHODS

Components

The new method of wear evaluation was demonstrated on 13 acetabular cups with a diameter of 28 mm (Table 1). All extracted acetabular cups were part of the Bicon-plus cup (Plus Endoprothetik AG, Rotkreuz, Switzerland; later Smith and Nephew). Ultra-high-molecular-weight polyethylene (UHMWPE) was made of RCH-1000 Chirulen (Quadrant PHS Deutsch-

Table 1. Characteristics of the patients enrolled in the study.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Gender</th>
<th>Weight (kg)</th>
<th>Body ms index</th>
<th>Age (years)</th>
<th>Side</th>
<th>Date of revision</th>
<th>Duration (months)</th>
<th>Type of patient</th>
<th>Reason for revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>66</td>
<td>24.24</td>
<td>67</td>
<td>Right</td>
<td>January 27, 2015</td>
<td>145</td>
<td>B</td>
<td>Periprosthetic fracture, wear</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>48</td>
<td>19.23</td>
<td>48</td>
<td>Right</td>
<td>October 10, 2011</td>
<td>126</td>
<td>B</td>
<td>Aseptic loosening</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>75</td>
<td>27.55</td>
<td>55</td>
<td>Left</td>
<td>November 5, 2012</td>
<td>120</td>
<td>B</td>
<td>Aseptic loosening – stem</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>63</td>
<td>24.01</td>
<td>61.5</td>
<td>Right</td>
<td>September 11, 2013</td>
<td>131.5</td>
<td>B</td>
<td>Aseptic loosening</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>103</td>
<td>32.51</td>
<td>52</td>
<td>Right</td>
<td>January 30, 2012</td>
<td>75</td>
<td>A</td>
<td>Painful hip</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>88</td>
<td>34.38</td>
<td>77</td>
<td>Right</td>
<td>January 22, 2014</td>
<td>48.5</td>
<td>B</td>
<td>Aseptic loosening</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>100</td>
<td>30.86</td>
<td>73</td>
<td>Left</td>
<td>May 14, 2013</td>
<td>89.5</td>
<td>A</td>
<td>Aseptic loosening – stem</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>58</td>
<td>21.05</td>
<td>43</td>
<td>Left</td>
<td>October 20, 2010</td>
<td>92.2</td>
<td>B</td>
<td>Fracture of the cup</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>56</td>
<td>23.31</td>
<td>63</td>
<td>Right</td>
<td>October 30, 2013</td>
<td>164</td>
<td>B</td>
<td>Aseptic loosening</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>72</td>
<td>26.77</td>
<td>53</td>
<td>Right</td>
<td>September 24, 2014</td>
<td>53.6</td>
<td>A</td>
<td>Aseptic loosening</td>
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<tr>
<td>11</td>
<td>F</td>
<td>77</td>
<td>26.96</td>
<td>69</td>
<td>Left</td>
<td>March 12, 2014</td>
<td>61.9</td>
<td>A</td>
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<tr>
<td>12</td>
<td>F</td>
<td>60</td>
<td>22.04</td>
<td>77</td>
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<td>43</td>
<td>B</td>
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</tr>
<tr>
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<td>68</td>
<td>29.05</td>
<td>59</td>
<td>Left</td>
<td>April 20, 2011</td>
<td>114.6</td>
<td>B</td>
<td>Aseptic loosening</td>
</tr>
</tbody>
</table>

*The Charnley classification tries to estimate the level of walking capacity, with class A having no disturbance in locomotion, class B with bilateral hip disease (or hip and knee) and normal findings in other weight-bearing joints, and class C with severe compromise of locomotion due to multiple joint involvement.

Both components.

Figure 1. Measuring by ATOS III Triple Scan 3D optical scanner.
tient consent, and the study was approved by the local Ethics Committee (as a part of project NT11049-5, Ministry of Health, Czech Republic).

New acetabular cups with a diameter of 28 mm were used as reference samples for validation of the method. The new acetabular cups were Durasul Low Profile Cups produced by Zimmer (size 50/28). Validation was replicated on three independent samples to eliminate measurement and manufacturing random errors.

**Optical scanning method**

Acetabular cups were measured using an 3D ATOS Triple Scan optical scanner (Figure 1). This optical system is based on active fringe projection and triangulation. The ATOS Triple Scan uses blue light technology in three viewing angles between the stereo camera and projector. With this approach, the measurements are not dependent on environmental factors and therefore it is not necessary to maintain constant environmental conditions during the measurements. A fringe pattern is projected on the object to be measured and the image is acquired using a two-camera system (Figure 2). The final scan is composed of multiple partial scans that are aligned according to the reference points detected by software.

For measurement of the acetabular cups, the reference points with a diameter of 0.8 mm were positioned on the surface of the cups outside their evaluated areas (GOM (21)). The measurement was carried out with MV170 lenses with a measurement volume of 170 × 130 × 130 mm calibrated in a small object arrangement. The lenses complied with VDI/VDE2634-3 (22). Further parameters of the measuring equipment are shown in Table 2.

The scanner was calibrated according to the procedures as defined by the producer. Results of calibration are shown in Table 3.

The surface of PE acetabular cups was too transparent for scanning and it was necessary to apply a layer of TiO₂ coating. An airbrush system was used to apply an approximately 3 μm coating (Palousek, et al. (23)). The acetabular cup was fixed in the middle of a rotary measurement table. The scanner was focused on the center of the acetabular cup at a scanning distance of 490 mm. Each individual scan consists of a large number of isolated points, technically described as a point cloud. Approximately six partial scans were used for the final scan to be used in postprocessing.

**Polygonization and definition of coordinate system**

After the measurement, the data were postprocessed using the software GOM Inspect (GOM mbH). First, the scan was polygonized and isolated points were defined as a point cloud. Approximately six partial scans were used for the final scan to be used in postprocessing.

**Table 2. Parameters of GOM ATOS III Triple Scan 3D scanner (Palousek, et al. (23)).**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>ATOS Triple Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera pixels (Mpx)</td>
<td>2 × 8</td>
</tr>
<tr>
<td>Measuring volume (mm)</td>
<td>170 × 130 × 130</td>
</tr>
<tr>
<td>Measuring distance (mm)</td>
<td>490</td>
</tr>
<tr>
<td>Lamp</td>
<td>LED</td>
</tr>
<tr>
<td>Focal length camera lenses (mm)</td>
<td>40</td>
</tr>
<tr>
<td>Focal length projector lens (mm)</td>
<td>60</td>
</tr>
<tr>
<td>Point distance (mm)</td>
<td>0.055</td>
</tr>
<tr>
<td>Reference points diameter (mm)</td>
<td>0.8</td>
</tr>
<tr>
<td>Camera position</td>
<td>Small object</td>
</tr>
</tbody>
</table>

**Table 3. Results of calibration.**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Results of calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation of calibration (pixels)</td>
<td>0.033</td>
</tr>
<tr>
<td>Optimized deviation of calibration (pixels)</td>
<td>0.020</td>
</tr>
<tr>
<td>Calibration of projector (pixels)</td>
<td>0.118</td>
</tr>
<tr>
<td>Optimized calibration of projector (pixels)</td>
<td>0.019</td>
</tr>
<tr>
<td>Angles of cameras (°)</td>
<td>27.2</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>24</td>
</tr>
<tr>
<td>Type of calibration object</td>
<td>CP40-170-40346</td>
</tr>
</tbody>
</table>

Figure 2. **Principle of ATOS 3D optical system.**
was reconstructed by removing and filling in damage caused by the surgeon during extraction of THR components (Figure 3). Surgical damage was identified after analyzing and considering the procedures used for extracting of THR implants. After these modifications, the polygonized geometry was smoothed with a surface tolerance of 3 $\mu$m to remove the surface roughness and possible coating defects that could distort the measurements.

A reference coordinate system for cup geometry was created using three fitting elements: a line, a point, and a plane.

The line represented the direction of the wear path (also described as a wear scar) and was used to identify the unworn parts of the samples. The 3D model was created on the basis of the nominal value of the acetabulum diameter. The direction of the wear scar was obtained by an initial comparison of the measured data with the nominal data of the new acetabular cup using the best-fit function of GOM Inspect. This comparison rendered a map of deviations that enabled us to infer the final direction of the wear scar (Figure 4).

The point was defined by the center of a sphere with a diameter corresponding to the original dimensions of the acetabular cup. The sphere itself was created using the Gaussian best-fit method on a cloud of points of the unworn region. A selection of points defining the unworn region is made manually according to the deviations from the ideal model. Cups with higher wear volumes have a clearly identifiable line between the worn and unworn regions. The selected points were then evaluated with three sigma statistical criteria enabling use of 99.73% of the points.

The plane was defined by the rim of the acetabular cup. A selection of points was performed automatically. A different method of point selection was used for antiluxation cups where the definition points were located only on the outer edge of the rim.

Polygonal data with the defined coordinate system were then used to determine the wear vector as a vector originating from the center of the unworn cup geometry to the most worn point on the inner surface of the cup. The center of the unworn region is defined by the point in the center of the coordinate system as described above. The center of the worn region is defined by the best-fit function applied to the selection of data in the direction of the wear scar. This can be calculated using the basic linear algebra equation for the angle between the two vectors (Figure 5; Uddin (24)).

The surface of the original acetabular cup was defined by fitting the primitives on unworn parts of the extracted
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The 3D scanning method was validated by a gravimetric comparison. Wear of the extracted cups was simulated simply by removing the material from new cups. The method specification and preparation of specimen can be found in ISO 14242-2 (5). The samples were cleaned of the PE particles to avoid loosening of the particles during scanning.

A Kern ABS 320-4N analytic balance was used to determine the weight loss. Reproducibility of the balance was 0.2 mg and the linearity was ±0.3 mg. The resolution was ±0.1 mg, which results in the volumetric uncertainty of ±0.106 mm³ for PE analysis. Gravimetric measurements were performed at temperatures between 22 and 23°C at a constant humidity level. Gravimetric measurements were taken five times in order to reduce a random error. The average of the measurements was used for the gravimetric comparison.

Validation of method

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Surface and volume creation

Polygonal data were exported to STL (STereoLitography) format for further postprocessing with Geomagic Design X (3D Systems GmbH) software (Figure 6b). First, the surface model was generated from the polygonal data using the Geomagic automag tool. The quality of this transformation was evaluated by comparing the rendered surface model with the polygonal data. This comparison showed a maximum deviation of 2 mm, which is a negligible uncertainty (Figure 7).

Next, the scanned geometry was trimmed and closed with a cylindrical geometry. Dimensions of the geometry were specified with respect to the extent of the volumetric wear. The cylindrical geometry had to include the whole articulation surface showing any material loss. The resulting surface model was suitable for transformation to the volumetric model using Geomagic tools (Figure 6c).

In the next step, the volumetric model was compared with the model of the original acetabular cup. The resulting comparison shows the volume of material released to a human body during the life cycle of the cup (Figure 6f).

Figure 6. Process of evaluation of volumetric wear.

Figure 7. Comparison of 3D scan and reconstructed geometry.
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The volume of the acetabular cup was multiplied by the density of UHMWPE (0.940 g/cm³; McKellop, et al. (25)). The validation samples consisted of three noncemented new acetabular cups with a size of 50/28.

Wear was carried out on a hip pendulum composed of two main parts: a base frame with an acetabular cup and a pendulum with a femoral head. The pendulum was allowed to oscillate freely in the flexion–extension plane. The simulator setup is described in detail elsewhere (Vrbka, et al. (26)). The parameter of weight loss was defined as the decisive parameter for validation. The articulating surface of the metal (CoCrMo) femoral head was scratched to increase the material loss (Figure 8). One test of volumetric wear lasted 1.5 h with a frequency of approximately 0.48 Hz. The test was performed without lubrication. Weights on pendulum arms ensured a total load of 2,080 N. The weight loss of the cups was measured in six cycles. The average weight loss after the sixth cycle was 0.075 g (80 mm³). This material loss simulates the wear rate as discussed in previous research (Dumbleton, et al. (27)).

The sample was weighed before and after testing. In order to mount the acetabular cup on the hip pendulum, it was necessary to fix the outer rim into the epoxy resin mixture. All tests were performed with this fixation; each cup was thoroughly cleaned before weighing and scanning.

RESULTS

Validation of 3D scanning method by gravimetric method

The material loss of the cups was measured in six cycles using both the gravimetric and 3D optical methods. Each cycle lasted 15 min and the process was replicated on three cups. Validation results are shown in Figures 9a–9c. As can be seen, the mean difference between the reference gravimetric method and the optical scanning method was

- -0.0040 g (range -0.0352 to 0.0089 g) for cup 1 (Figure 9a).
- -0.0021 g (range -0.0159 to 0.0051 g) for cup 2 (Figure 9b).
- -0.0029 g (range -0.0286 to 0.0067 g) for cup 3 (Figure 9c).

A significant difference in volumetric wear values measured with the gravimetric method and optical scanning method was present after the first 15-min cycle. This difference may have occurred due to the plastic deformation process. Polygonal data for each measurement were created on average from 191,500 points. This number of points ensures a high quality of surface transformation with deviations less than 0.002 mm as shown in Figure 7. A volume calculation based on surface data was carried out using the CAD system calculation algorithm. The calculation was replicated using three independent software systems. The difference was less than 0.1 mm³; hence, the deviation of the calculation algorithm is considered negligible.

In order to demonstrate the time efficiency of the method, the duration of each step in the measurement process was recorded. Results are shown in Table 4.

Analysis of extracted acetabular cups

This study analyzed 13 extracted acetabular cups using the optical scanning method based on the principle of fringe projection and triangulation. The cups were scanned using the ATOS III Triple scan to create digital representations of articulating surfaces of cups. Results of measurements and the analysis of 13 extracted UHMWPE bearing cups are shown in repeatability analysis of measurement. The results were supported by a study of survival of replacements produced by Bicon-plus where the mean linear wear of the Bicon-plus PE was 1.8 mm, which corresponds to 0.12 mm/year (Ottink, et al. (27)).
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THE TECHNOLOGY OF KAO SURFACTANTS IN METALWORKING FLUIDS
A significant difference in volumetric wear values measured with the gravimetric method and optical scanning method was present after the first 15-min cycle. This difference may have occurred due to the plastic deformation process. Polygonal data for each measurement were created on average from 191,500 points. This number of points ensures a high quality of surface transformation with deviations less than 0.002 mm as shown in Figure 7. A volume calculation based on surface data was carried out using the CAD system calculation algorithm. The calculation was replicated using three independent software systems. The difference was less than 0.1 mm³; hence, the deviation of the calculation algorithm is considered negligible.

![Figure 9b. Comparison of validation test results of 3D scan and gravimetric method—Cup 2.](image)

![Figure 9c. Comparison of validation test results of 3D scan and gravimetric method—Cup 3.](image)
In order to demonstrate the time efficiency of the method, the duration of each step in the measurement process was recorded. Results are shown in Table 4.

### Analysis of extracted acetabular cups

This study analyzed 13 extracted acetabular cups using the optical scanning method based on the principle of fringe projection and triangulation. The cups were scanned using the ATOS III Triple scan to create digital representations of articulating surfaces of cups. Results of measurements and the analysis of 13 extracted UHMWPE bearing cups are shown in Table 5.

The nominal inner diameter of the extracted acetabular cups was 28 mm. The outer diameter varied; however, this had no influence on the results. Acetabular cups exhibited a mean volumetric wear of 395.53 mm³ (range = 51.80–1,119.70 mm³). The mean wear rate was 44.37 mm³/year (range = 9.98–125.85 mm³, SD = 32.45 mm³). Each measurement was replicated twice in order to eliminate scanning errors. Small differences between the measurements had no impact on quantification of volumetric wear. This can be supported by the repeatability analysis of measurement. The results were supported by a study of survival of replacements produced by Bicon-plus where the mean linear wear of the Bicon-plus PE was 1.8 mm, which corresponds to 0.12 mm/year (Ottink, et al. (28)). Another study validates the results of the scanning method with a widely used radiographic method where the volumetric wear of the failed replacement ranged from 730 to 813 mm³ (Ilchmann, et al. (29)).

A new acetabular cup produced by the same producer as the extracted cups (Endoplus GmbH) was used as a reference sample for repeatability of the optical scanning method. Results of the repeatability test are shown in the graph below (Figure 10). Repeatability was evaluated on the basis of the software-determined value of the inner diameter using the best-fit function. The method was set to the Gaussian statistic method using point filtration three sigma. Measurements were replicated 10 times. Results of measurement were obtained only from the articulating surface; the rim and the outer diameter were not taken into account when determining the volumetric wear. Roughness and roundness of the measured object were neglected. The mean variation of the inner diameter was 0.005 mm (range = 28.624–28.643 mm, SD = 0.005 mm).

### DISCUSSION

The results show that the 3D optical method is suitable for measuring the THR wear of PE acetabular cups and thus it represents an effective alternative to the CMM method, which has, in some cases, reached the limits of its use.

One of the major limitations of the CMM method is a limited number of measured points collected for designing the geometry. Collecting a larger number of surface points using the

---

**Table 4.** Time efficiency of scanning method.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Approximate time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaning of acetabular cup</td>
<td>10</td>
</tr>
<tr>
<td>Application of titanium coating</td>
<td>15</td>
</tr>
<tr>
<td>Placement of a reference points</td>
<td>10</td>
</tr>
<tr>
<td>Scanning process</td>
<td>12</td>
</tr>
<tr>
<td>Polygonization</td>
<td>5</td>
</tr>
<tr>
<td>Repair of geometry</td>
<td>10 (depends on rate of damage)</td>
</tr>
<tr>
<td>Transformation on surface</td>
<td>20</td>
</tr>
<tr>
<td>Transformation on volume</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>90</td>
</tr>
</tbody>
</table>

**Table 5.** Quantification of volumetric wear explanted acetabular cup.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Duration (months)</th>
<th>Size of implants</th>
<th>Type of implant</th>
<th>Material loss (mm³)</th>
<th>Material loss per year (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>145</td>
<td>4/28</td>
<td>PE insert standard</td>
<td>1,119.7</td>
<td>92.66</td>
</tr>
<tr>
<td>2</td>
<td>126</td>
<td>5/28</td>
<td>PE insert standard</td>
<td>528.97</td>
<td>50.38</td>
</tr>
<tr>
<td>3</td>
<td>120</td>
<td>4/28</td>
<td>PE insert antiluxation</td>
<td>99.81</td>
<td>9.98</td>
</tr>
<tr>
<td>4</td>
<td>131.5</td>
<td>4/28</td>
<td>PE insert standard</td>
<td>752.01</td>
<td>68.63</td>
</tr>
<tr>
<td>5</td>
<td>75</td>
<td>6/28</td>
<td>PE insert standard</td>
<td>170.98</td>
<td>27.36</td>
</tr>
<tr>
<td>6</td>
<td>48.5</td>
<td>4/28</td>
<td>PE insert standard</td>
<td>162.63</td>
<td>40.24</td>
</tr>
<tr>
<td>7</td>
<td>89.5</td>
<td>5/28</td>
<td>PE insert standard</td>
<td>299.66</td>
<td>40.18</td>
</tr>
<tr>
<td>8</td>
<td>92.2</td>
<td>4/28</td>
<td>PE insert antiluxation</td>
<td>966.92</td>
<td>125.84</td>
</tr>
<tr>
<td>9</td>
<td>164</td>
<td>3/28</td>
<td>PE insert standard</td>
<td>584.86</td>
<td>42.80</td>
</tr>
<tr>
<td>10</td>
<td>536</td>
<td>5/28</td>
<td>PE insert antiluxation</td>
<td>69.46</td>
<td>15.55</td>
</tr>
<tr>
<td>11</td>
<td>61.9</td>
<td>4/28</td>
<td>PE insert antiluxation</td>
<td>152.98</td>
<td>29.66</td>
</tr>
<tr>
<td>12</td>
<td>43</td>
<td>7/28</td>
<td>PE insert standard</td>
<td>51.80</td>
<td>14.46</td>
</tr>
<tr>
<td>13</td>
<td>114.6</td>
<td>4/28</td>
<td>PE insert standard</td>
<td>182.05</td>
<td>19.06</td>
</tr>
</tbody>
</table>
CMM method is relatively time consuming. However, larger numbers of collected points are crucial for credible reconstruction of the unworn geometry and hence for a more precise analysis of wear. Previous studies showed that the mesh definition and performance of the meshing algorithms can significantly influence the obtained results (Bills, et al. (6); Lord, et al. (12); Carmignato, et al. (30)).

This limitation of the CMM method can be solved by the optical scanning method, which allows for collecting a larger number of points in a shorter time. Approximately 191,500 points collected on a single 28-mm acetabular cup can help to create a better surface visualisation. The resulting close point spacing solves the problem of curvature of the elements (Lu and McKellop (31)) and the problems related to the latitudinal and longitudinal mesh pattern (Bills, et al. (6)). Moreover, the ability to produce fully three-dimensional wear contours allows us to locate the wear scar with high reliability. The direction of the wear scar helps to define the unworn area of the acetabular cup. A right selection of points in the unworn area can then have a significant influence on the obtained result.

It is therefore important to carefully select the measured points of the unworn area to create the original geometry and to define the diameter. One of the options is to use GOM Inspect software. This approach was used in this study, taking advantage of compatibility of the results with the CAD software for further analysis. Another option is to use a fitting histogram for a precise selection of the unworn area points (Uddin (24)).

Another advantage of the optical 3D method is the ability to define the wear vector on the basis of decentration of the worn region position against the original, software-generated geometry (Figure 5). Parameters of the resulting wear vector can be then compared with the results obtained by medical methods (Dai, et al. (32)).

Data collected through the optical scanning method can be also suitable as input parameters for finite element prediction models (Uddin and Zhang (33)).

Despite the clear advantages of the optical scanning method, this method poses some challenges and limitations. The main limitation is the precision of the optical 3D scanner, which was established by repeatability of the measurement and parameters of the device. The optical scanning precision as established for the purposes of this study did not reach the levels of accuracy of the CMM method. The maximum accuracy of CMM is approximately ±1 μm. An evaluation of measurement method uncertainty, following ISO/IEC98-3 (34), is fundamental for both establishing a metrological traceability and allow-
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This article presents a new method of determining volumetric wear using an optical 3D scanner. This method was demonstrated on 13 extracted UHMWPE acetabular cups with various ranges of wear.

The study consists of three parts: (1) description of the optical method used for volumetric wear analysis, (2) validation of the methodology, and (3) application of methodology on the extracted acetabular cups.

CONCLUSION

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Calumet Acquires Biosynthetic Technologies

Indianapolis-based, Calumet Specialty Products Partners, L.P., a leading independent producer of specialty hydrocarbon and fuels products, announces the acquisition of Biosynthetic Technologies, LLC.

Biosynthetic Technologies is a start-up company and developer of proprietary renewable technology focused on the conversion of sustainable plant oils into high-performance synthetic base stocks. These unique estolides exhibit exceptional qualities for high-performance lubricants while also meeting stringent environmental specifications for biodegradability, bioaccumulation and toxicity. Calumet plans to develop and commercialize these renewable esters at its existing esters manufacturing facility in Missouri. The acquisition of Biosynthetic Technologies was completed in partnership with The Heritage Group, a technology partner whose business model offers synergies with Calumet that will maximize the value of the acquired technology portfolio.

“The acquisition of Biosynthetic Technologies and its technological capabilities align very well with the partnership’s specialty products-focused growth strategy and our vision to be the premier specialty petroleum products company in the world,” says Tim Go, Calumet CEO. “This acquisition, alongside the recently announced opening of our new research and development facility in Indianapolis, are indicative of Calumet’s commitment to innovation. The technology and expertise we have acquired will help extend our existing esters business into new, forward-thinking product formulations with exceptional qualities for which the Calumet name represents.”

Bruker Acquires Anasys Instruments

Billerica, Mass.-based, Bruker announces it has acquired Anasys Instruments Corp., a privately held company that develops and manufactures nanoscale infrared spectrocscopy and thermal measurement instruments.

This acquisition adds to Bruker’s portfolio of Raman and FTIR spectrometers, as well as to its nanoscale surface science instruments such as atomic force microscopy and white-light interferometric 3D microscopy.

Headquartered in Santa Barbara, Calif., Anasys Instruments Corp. has pioneered the field of nanoprobe-based thermal and infrared measurements. Its industry-leading nanoIR™ products are used by premier academic and industrial scientists and engineers in soft-matter and hard-matter materials science and in life science applications. Recently Anasys introduced even higher performance with 10 nanometer resolution nanoIR imaging.

“We are very excited to add this strategic, high-growth area to our portfolio of nanoscale microscopy and spectroscopy measurement products,” says Dr. Mark R. Munch, president of the Bruker NANO Group. “There are tremendous application and technology synergies that will benefit our customers.”

Roshan Shetty, co-founder and former CEO of Anasys, says, “We are very happy to have found a company like Bruker to take the business to the next level. We feel that Bruker’s history in innovative instrument research and Bruker’s global reach will build on our own history of unique and pioneering achievements in thermal and nanoIR measurements.”

Des-Case acquires RMF Systems

Goodlettsville, Tenn.-based, Des-Case Corp., a market leader in desiccant breathers and manufacturer of specialty products that improve process equipment reliability and extend lubricant life for companies around the world, announces its acquisition of RMF Systems from Doedijns Group International, an experienced specialist in desiccant breathers, filtration systems, analysis and monitoring solutions to maintain hydraulic oil and lubricant cleanliness. The acquisition of RMF, Des-Case will provide a broader range of solutions, greater customer convenience and deeper professional expertise.

RMF Systems is an experienced specialist in the field of solutions for filtration, analysis and monitoring of hydraulic oil and lubricants. The company is at the forefront of the development of products in the field of filtration solutions and analysis equipment.

Des-Case holds the leading position in the North American breather market and also provides world-class filtration and transfer systems of all shapes and sizes, while RMF is a major player in the European filtration market with particular focus on hydraulic solutions. Together Des-Case and RMF will help companies make their equipment investments last longer through an
extensive combined product line that will provide solutions of superior breadth and depth for any contamination problem.

**ExxonMobil Basestocks Strengthens Branded Distributor Network**

*ExxonMobil* announces it has signed a new distributor agreement with *Zestcor*, an experienced sales, procurement and supply chain management company in South Africa. The agreement is designed to support an efficient and reliable supply of high-quality base stocks in South Africa and the sub-Saharan region.

Zestcor has a distinct local business footprint in the South African petrochemicals industry as a Broad-Based Black Economic Empowerment Company. This commercial relationship will expand ExxonMobil’s global presence and provide local customers additional access to base stocks capable of meeting a broad range of blending needs.

“We are committed to providing a reliable supply of high-quality products to our valued customers around the world,” says Julia Ruessmann, EAME basestocks and specialties sales manager at ExxonMobil. “Zestcor not only complements ExxonMobil’s position in South Africa by providing local supply chain solutions but supports our long-term commitment to meeting customer demands in country.”

Zestcor is uniquely equipped to receive bulk ExxonMobil shipments and handle both truck loading and delivery, as well as pipeline transfers with its strategically placed bulk onshore tank storage facilities at Bidvest Tank Terminals in Island View, Durban.

“At Zestcor, product integrity and quality control are at the forefront of what we do,” says Nic Dunn, director at Zestcor. “Partnering with a global leader like ExxonMobil, which not only shares these values but promotes them as a pillar of their business operations, makes perfect sense for us. We also believe that South Africa will benefit by having additional local access to high-quality base stocks.”

**Atlas Oil and TOTAL Announce Lubricants Partnership**

Taylor, Mich.-based, *Atlas Oil Co.* is now a *TOTAL Specialties USA, Inc.* (based in Houston) authorized lubricants distributor, cementing Atlas’ vision of a single-source service model of premium lubricants and bulk fuel supply for its customers.

“We know our customers expect only the best products and services, which is why we now proudly offer TOTAL lubricants as part of our oil field services,” says Atlas’ president of frac and rig fueling Michael Meredith. “As the partner of choice for many of the major E&P companies in the country’s largest
shale plays, our partnership with TOTAL is a big win for everyone.”

TOTAL’s and Atlas’ successes are driven by many of the same values, including safety, collective responsibility, perpetual innovation and a family-like team spirit. TOTAL is the fourth largest oil and gas company in the world and is recognized internationally as a global energy leader. Its high-performance lubricants are designed to extend the life of equipment and ease the cost of maintenance and repairs.

Atlas’ lubricants distribution will fall under its oilfield services division in select markets with a focus on onshore drilling rigs, frac trucks and gas compression units with supply capabilities to match customers’ consistent oil, grease and hydraulic fluid needs. The company plans to expand its lubricants services nationwide and into their commercial fueling, retail and emergency service divisions throughout 2018.

“We are extremely excited to partner with such an innovative company like Atlas,” comments Christophe Doussoux, senior vice president, lubricants for TOTAL Specialties USA, Inc. “TOTAL has the industry-leading product line and Atlas brings years of excellence in customer service. I am confident this partnership will lead to immense growth for both parties.”

ExxonMobil Completes Next Phase at Singapore Refinery

ExxonMobil has successfully completed the heavy lift of a new lubes reactor at its Singapore Refinery in Jurong. The reactor is a crucial piece of equipment tied to ExxonMobil’s ongoing expansion project to increase production of high-quality EHCTM base stocks, which are designed to meet new and upcoming finished lubricant specifications, including ILSAC GF-6, API SP and API CK-4/FA-4.

Enabling advanced applications, particularly in the automotive sector, these quality improvements will help customers achieve short-term cost savings through blending optimization and long-term savings through reformulation.

“We are committed to meeting our customers’ requirements by offering industry-leading, reliable supplies of our CORETM Group I and EHC Group II base stocks,” says Vipin Rana, Asia Pacific basestocks and specialties sales manager. “Our continued investment demonstrates our long-term focus on the business and commitment to meeting the growing demand in the Asia-Pacific region.”

The new lubes reactor, weighing 800 tons, 46 meters long and four meters wide, was one of the largest and heaviest lifts in recent years at the Singapore Refinery. The lift was completed earlier this year using a 1,200-ton gantry crane and 600-ton tailing crane.

The refinery expansion project continues to progress toward its scheduled completion in the second quarter of 2019. When completed, ExxonMobil will strengthen its global supply of EHC Group II base stocks, enhancing the Singapore site’s competitiveness.

Italmatch Chemicals acquires Detrex Corp.

Genoa, Italy-based, Italmatch Chemicals, a global specialty chemical group, has acquired Detrex Corp., an American company headquartered in Cleveland, Ohio, and specialized, through its subsidiary The Elco Corp., in the production of high-performance lubricant additives for industrial applications and high-purity hydrochloric acid.

The acquisition is coherent with the internationalization process undertaken by the group in the last few years with a particular focus on the American market and confirms the aim of expanding and broadening current production portfolio. The transaction follows the recent acquisition of Sudamfos do Brasil, a leading Brazilian distribution company specialized in marketing of phosphonates, phosphates and other special chemical products, and approximately one year after the acquisition of Compass Chemical International, a chemical company independent of North America, leader in the production and marketing of special additives for water and oil and gas treatment.

Sergio Iorio, CEO of Italmatch Chemicals Group, says, “We are excited about this acquisition because we have known Elco, its products and management team for many years. Elco will bring highly complementary products and geo coverage, commercial and industrial synergies as Italmatch is focused on EMEA/AP markets and Elco on NA/LATAM markets, with sales and organizational synergies in other regions. In addition, from a product portfolio point of view, Italmatch is a leader in special synthetic base stock and antiwear additives, and Elco has a distinctive and very complementary position in EP additives and ad-pack for grease and MWF.”

Thomas E. Mark, president and CEO of Detrex Corp., says, “The acquisition by Italmatch Chemicals represents for Detrex-Elco a great opportunity to be an essential part of an exemplary business model in the field of specialty chemicals. Elco and Italmatch Chemicals have the same high standards of production and have a very similar mission and overall corporate culture.”
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Sea-Land Chemical
Expands Operations Team

Westlake, Ohio-based, Sea-Land Chemical Co. adds David Smith as business manager for the subsidiary Sea-Land Chemical Europe Ltd. Smith brings more than 20 years of experience in the chemical industry, most recently serving as a global key account manager for Oleon NV for the past seven years. Career accomplishments also include seven years of experience in business operations as the purchasing manager for Koras Group.

“With the healthy growth of our business in Europe, bringing on someone with David’s industry knowledge and operations experience is vital to our continued success,” states STLE-member Craig Lundell, senior vice president of commercial operations and Europe. “Our lubricant customers are becoming more global with their formulation and business requirements. We are confident that under his leadership, we are well positioned to meet the expanding raw material and logistics needs of our customers globally.”

STLE-member Robert Stubbs remains with the company as a technical advisor, serving as a technical resource for customers in Europe. Kevin Bolt will continue to support the Eastern Europe and Asia market in his current role for Sea-Land Chemical Europe.

“Since its inception in 2011, Rob has done a phenomenal job creating, leading and guiding the business development activities of our European operations,” states Lundell. “We are enthusiastic about the future of our European business and the team of talented individuals we have in place to support our customers and supplier partners.”

Pilot Chemical Hires
Business Line Manager

Christina May has been named Pilot Chemical Co.’s (based in Cincinnati, Ohio) new business line manager. She will oversee the direction and performance of Pilot Chemical’s product line.

May brings more than 15 years of experience in product sales and chemistry and most recently served as market development manager at Michelman in Cincinnati. She earned a bachelor’s degree in chemical engineering from the University of Cincinnati and a master’s degree in business administration from University of North Carolina at Chapel Hill.

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.
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Dr. Edward P. Becker receives Gold Award

The Engineering Society of Detroit honors STLE past president.

By Susan Thwing

Dr. Edward Becker, PE, was awarded The Engineering Society of Detroit’s (ESD) Gold Award in March at the society’s Gold Award Reception and Recognition. The ESD Affiliate Council, made up of 100-plus technical societies, presents the award each year to honor an outstanding engineer or scientist who has distinguished himself/herself through outstanding achievement and service.

Becker was nominated by STLE and endorsed by ASM International.

In its 47th year, the Gold Award has honored presidents of companies and leaders of industry, professors and engineers, entrepreneurs and innovators for their dedication and commitment to their professions. Becker, former STLE president, holds a doctorate in mechanical engineering from the University of Michigan and is a lifetime member of Mensa, the largest and oldest high-IQ society in the world.

“I am overwhelmed and deeply grateful to be chosen,” Becker said at the event. “It is a tremendous honor to be among the Gold Award recipients.”

Becker retired from General Motors after more than 30 years, mostly working in the powertrain division on a variety of GM engines and transmissions. During that time he developed processes that resulted in nine U.S. patents.

“Working at GM was an opportunity to collaborate with the best in the business. There was a synergy that brought out the inspiration in you, and the patents were a team effort,” he explains.

Don Cohen, an instructor at Michigan Metrology, nominated Becker for the award. The two met while working at GM nearly 20 years ago.

“His background is hugely impressive. At one point he went back to school at the University of Michigan to earn his PhD. While there, he was a student of the people who created the field of tribology. His lineage is the founding of the industry,” Cohen explains.

Cohen is referring to Becker’s instruction by Kenneth Ludema, a University of Michigan professor highly renowned for his work in friction and the wear of materials. Cohen says he is inspired by Becker’s energy and dedication to the field.

“Edward Becker is highly involved in STLE, working his way up from an initial board membership to being president of the international society. At STLE you receive a medal for each post you hold that you pin to your jacket—Edward looks like a five-star general at the meetings,” he explains.

After retirement, Becker founded Friction & Wear Solutions, LLC, a consulting firm dedicated to solving tribology problems. The company celebrates its fifth anniversary in 2018. Maintaining a close network of colleagues and business contacts has helped with the business’ success. “You have to maintain your network, and I am fortunate in that way. If someone contacts me for work I’m not an expert in, I can refer that person to someone I know,” he says.

Becker and his wife, Jean Becker, PhD, also a lifetime member of Mensa, travel internationally in their spare time having visited more than 100 countries and seven continents. They also participate in bridge tournaments.

For future engineers, Becker has one particular piece of advice: “Keep trying, keeping looking forward.”

Susan Thwing is editor of TechCentury magazine, published by The Engineering Society. Contact her at sthwing@esd.org. Reprinted by permission of The Engineering Society of Detroit.
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A WORLD OF LUBRICATION UNDERSTANDING
A tribute to the Father of Tribology:
Professor H. Peter Jost

The contributions of this industry giant will never be forgotten.

By Dr. Raj Shah & Shana Braff
Koehler Instrument Co.

Most people take for granted the non-slip shoes that keep them steadily on their soles all throughout the hustle and bustle of the work week and then staying upright dancing the hustle (okay, maybe not since the 1970s) all Friday night or the anti-slip bathtub that allows you to sing in the shower without fear of falling flat, except maybe vocally.

Non-slippery shoes and anti-slip bathtubs and showers are all things tribology has an instrumental part in. In addition, its role is in ensuring that other types of technology we rely on daily perform properly, such as the critical function brakes provide in any form of transportation. This is yet another invaluable service we owe to the rarefield of tribology; furthermore, even fewer people know the name Peter Jost, who is often considered one of the founders of the discipline of tribology.

They say money talks, so it’s no surprise that tribology only became widely acknowledged in the 1960s after an eye-opening English study: The Jost Report. This eponymous report was published by Jost, a British mechanical engineer who would become known as the founder of tribology. The report discovered that enormous financial losses were occurring due to the result of friction and corrosion. However, knowledge of these factors is virtually as old as time: The ancients, as far back as Paleolithic times, understood the need to control these forces. The ancient Egyptians reduced friction by using wheels and lubricants in their chariot bearings and in the contraptions used to transport the large loads required to build the pyramids.

Jost passed away in June 2016 at the ripe-old age of 95, after a long, illustrious career. He was educated at Liverpool Technical College and Manchester College of Technology. He started his career as an apprentice at Associated Metal Works in Glasgow. At just 29, he was general manager of the international lubricants company Trier Brothers and went on to serve as a director and chairman of several technology and engineering companies. He also served on several industry councils and, until his death, was president of the International Tribology Council and a lifetime member of the council of the Parliamentary & Scientific Committee. He also was an honorary fellow of the Institution of Engineering and Technology, the Institution of Mechanical Engineers and the Institute of Materials.

He was appointed a Commander of the Most Excellent Order of the British Empire (CBE) in 1969, and also was honored by the heads of state of France, Germany, Poland, Austria and Japan, and in 1992 became the first honorary foreign member of the Russia Academy of Engineering. He held two honorary professorships and 11 honorary doctorates including, in January 2000, the first Millennium honorary science doctorate. Finally, in 2009, well into his golden years when most would be content to rest on their laurels, Jost was still a pioneer in the industry and looking to the future when he co-launched the principles of Green Tribology, leading the way for the first Green Tribology World Congress. Shortly before his death, he was elected an Honorary Fellow of the Royal Academy of Engineering. However, he passed away before the Academy’s AGM at which this was announced.

Jost’s groundbreaking report, which was commissioned by the British government, shed light on the fact that, for the first time, problems of lubrication in engineering were primarily issues of design. Their solutions, Jost postulated, required a variety of skills from scientific disciplines, other than mechanical engineering, including chemistry and materials science, solid body mechanics and physics. Jost and his team calculated that enormous financial losses could be evaded as a result of fewer breakdowns causing lost production, lower energy consumption, reduced maintenance costs and longer machine life. In response to the Jost report, several national tribology...
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centers were initiated in Britain, although originally it was Britain’s competitors who took the lead in the immediate aftermath of the revelatory report.

While tribology is a relatively new science, paradoxically, Jost paid a debt to those scientific geniuses who paved the way before him and acknowledged that the concepts behind it had been extant for centuries.

Tribology has come a long way since it was first discovered, thousands of years ago, during the Paleolithic Period, when a rudimentary bearing was fashioned from the bone of an antler. The Promethean innovation also was used as a tool to spark fire solely by friction. Since the Babylonian wheel and tripartite disc wheel used in Mesopotamian chariots were created during 3500 B.C. and 2800 B.C., respectively, such tribological progress has been imperative to sustaining the very survival of mankind, from that time up through today and beyond.

It was none other than Leonardo da Vinci who postulated that friction is proportional to load and independent of the area of the item being moved. At this seminal moment an inchoate version of tribology was approached as a legitimate science. In 1687 Sir Isaac Newton weighed in, observing the fluid properties that affect lubricated friction, and in 1699 Guillaume Amontons elucidated da Vinci’s two hypotheses, elevating them to incontrovertible laws.

Finally in 1780 the last in a triumvirate of classic friction laws was decreed with C.A. de Coulomb’s research, which presented the theory that friction is independent of sliding speeds. Modern scientific studies were conducted in the late 1930s by F.P. Bowden and David Tabor, who gave the discipline the moniker tribophysics, perhaps unsurprisingly, that peculiar portmanteau never caught on, paving the way for Professor Jost to coin the science’s official name: tribology.

Tribology is a more apt term than tribophysics due to the interdisciplinary nature of the science, which is a mélange of chemistry, physics, material science, mechanical engineering and increasingly, biology. However, what really helped tribology make its mark was the price tag Jost’s report attributed to the cost of wear and tear. The pecuniary benefit of tribology has inspired numerous studies since. While enormous savings could be achieved with more adept tribological practices, considering the wear on tires, shoes and clothes alone, which is easily in the billions, the benefits of better tribology protocols far exceed the financial. With its dramatic role in improving the bearings in car and airplane engines so that failure is virtually impossible, tribology also veers into lifesaving territory. This, of course, is just one example. In just about every field imaginable, tribological advances are synonymous with technological innovation. For example, a large portion of global energy production is consumed by extraneous friction and wear, which implies that more effective solutions to tribological concerns could lead to superior energy efficiency and, therefore, a cleaner, more salubrious environment.

As the wheel of time turns, tribology will continue to be of incalculable significance to achieving sustainability and energy efficiency for a variety of applications in daily living. So the next time you’re taking an evening stroll, pressing the brakes on your car or performing any of the countless quotidian activities where friction is required, take a moment to silently thank the unsung field of tribology, the non-squeaky wheel of the scientific world that keeps all things running smoothly and to its aptly unassuming adoptive father, who took a nameless, orphaned science and gave it its respective place in the annals of scientific innovation.

Dr. Raj Shah is a director for sales, marketing and technical services with Koehler Instrument Co. at their manufacturing facilities/corporate headquarters in New York. You can reach him at rshah@koehlerinstrument.com. Shah is receiving the STLE P.M. Ku Meritorious Award, which recognizes outstanding and selfless achievements for the society, at the 2018 STLE Annual Meeting in Minneapolis.

Shana Braff is a customer service specialist with Koehler Instrument Co. in Holtsville, N.Y. You can reach her at (631) 589-3800 or sbraff@koehlerinstrument.com.
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SKF introduces its Lincoln mechanical grease overflow prevention system. Designed to prevent hazards associated with reservoir overfilling, this product improves worker safety and minimizes environmental concerns caused by this type of spill. Easy to install and simple to operate, the system reduces the manpower needed for reservoir filling, freeing personnel for other tasks. In addition, the mechanical grease overflow prevention system can be used with a wide range of supply/filling pumps and is compatible with any pump using a FlowMaster reservoir. Operating mechanically with no electricity required, the system features heavy-duty, all-steel construction with anti-corrosion plating to withstand harsh environments. Its high-pressure system shut-off valves are available in 1/2-inch NPT. The mechanical grease overflow prevention system can be operated with or without a Lincoln grease level sensor, which enables it to be connected to a grease level gauge at the fill station or in the cab. The mechanical grease overflow prevention system is suitable for mining, aggregate and industrial applications, as well as for use on off-road construction equipment.

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Lonza announces the latest addition to its cell-culture product portfolio—the Quasi Vivo® System. The Quasi Vivo® device consists of an advanced, interconnected fluidics system to create more physiologically relevant cell-culture conditions, helping researchers improve the predictive value of their studies. This new product offering from Lonza is a result of a worldwide marketing and distribution agreement with Kirkstall—a biotechnology company based in Rotherham, UK. A common issue faced by drug discovery scientists who use conventional in vitro culture systems is their poor translatability to humans. To address this problem, Kirkstall developed the Quasi Vivo® System, which consists of interconnected cell-culture chambers and a peristaltic pump to create a continuous flow of media over cells. As a result, cultures are exposed to more physiologically relevant conditions, increasing the predictive value of in vitro experiments. The Quasi Vivo® System is available with three different culture chambers (QV500, QV600 and QV900) to support a wide range of applications, including submerged cell culture, co-culture and modeling of air-liquid and liquid-liquid interfaces.

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For additional questions about the app, please contact Bruce Murgueitio at bmurgueitio@stle.org.

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Exhibitor Appreciation Hour

Monday and Tuesday
May 21 & 22
3-4 pm both days

Minneapolis Convention Center

Refreshments will be served!

The trade show is a major component of STLE's Annual Meeting. In 2018 STLE is making it even easier for you to fit a visit to the exhibition into your personal itinerary with two hours of dedicated exhibit time—no need to worry about missing an education course or technical session!

Come view the newest products and services from the lubricant industry’s leading companies. More than 100 exhibitors are in Minneapolis looking to do business with you.

As part of the Exhibitor Appreciation Hour, Evonik Oil Additives is holding raffles on Monday and Tuesday, May 21 and 22, at 3:30 pm in the exhibit hall. You must be present at Evonik Booth 103 at time of drawing to win. Evonik is raffling three Fitbit Alta activity trackers.

2018 Exhibit Schedule

Monday: Noon-5 pm (Exhibitor Appreciation Hour 3-4 pm)
Tuesday: 9:30 am-Noon & 2-5:30 pm (closed for Presidents Luncheon - Noon-2 pm. Exhibitor Appreciation Hour 3-4 pm)
Wednesday: 9:30 am-Noon

Exhibitors: To reserve a spot at the 2019 STLE exhibition at the Omni Nashville Hotel in Nashville, Tenn., contact Tracy Nicholas VanEe at (630) 922-3459, tnicholas@stle.org.

Download the 2018 STLE 365 App. Annual Meeting section sponsored by Focus Chemical.
Q.1 How has STLE certification benefitted your career?

Has someone with an STLE certification ever offered you technical or career advice/help?

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Based on responses sent to 15,000 TLT readers.
Technical research in the lubricants industry is peer reviewed, but how does a potential customer, vendor or employer “peer review” a person? For nearly 2,000 industry professionals, the answer is STLE certification. Whether it’s Certified Lubrication Specialist™, Oil Monitoring Analyst™ I and II or Certified Metalworking Fluids Specialist™, STLE’s certifications are the mark of credibility in the lubricants industry. Many readers say their STLE certifications resulted in an immediate salary increase, others report that it was the key differentiator when competing for a new position, and some stated that, for their jobs, STLE certification is a requirement. A common theme among survey respondents is that STLE certification means more to employers than customers. However, savvy readers noted that educating customers about their STLE certification actually is an opportunity in disguise. As one noted: "People ask what all those letters after your name on the business card mean, and that opens the door for a conversation into your expertise and experience in the field.”

**CLS** is a required certification for my job. It gives our company credibility with our customers.

**Being certified as a CLS** has helped my career. The certification made me the go-to guy within my organization for technical guidance. Being a resource within the organization led to management opportunities. While the CLS means less to customers, having the knowledge to solve their problems has allowed me to build trust and earn business.

**Being STLE certified made me the preferred candidate for my current job.**

I believe my OMA I is helping move our used oil analysis from an added service to more of a value proposition.

The benefit: having a third-party verify that I know what I’m talking about. Plus it revealed to me the need to always stay up to date on technical changes. You cannot know everything, but you can know where to go to find answers.

**It has not advanced my career, but it has given me more credibility with customers when it is explained to them.**

**STLE certifications are an indication to the business world that I am a recognized expert in the area of lubrication.**

**As a salesman, I can offer better solutions to key plant personnel to help them solve their problems.**

---

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It is one of my most cherished certifications, but as far as I know it hasn’t helped me.

CLS certification is highly respected in my industry and adds credibility to my work.

I have used my CLS certification to propel my career into a sustainable job with a major lubricants company. Customers understand the credentials and are more motivated to conduct business with someone with CLS.

My last employer required it.

I was recognized by my peers because I was a founding member of the CLS Committee.

Having or obtaining a CLS was a requirement for a position I held for nearly 10 years.

CLS and OMA I have opened a lot of doors for me as a lubricant-distributor salesperson. People ask what all those letters after your name on the business card mean, and that opens the door for a conversation into your expertise and experience in the field. It really helps with the flow of information between myself and a potential customer.

I believe my CMFS certification helped me secure a new job. It was of significant value to my new employer, a metalworking fluid manufacturer.

It’s improved my self-confidence and added credibility with clients and suppliers.

It illustrates to customers that I have first-hand, in-plant, practical knowledge of lubricants and their applications within various plant environments.

It has done very little for my career. There are very few companies that recognize it or even know what it is. However, I am very proud of it and will always maintain it.

With more sophisticated customers, once they understand what the CLS designation means, it does appear to help differentiate us against price-driven sales efforts. The trick is that the majority of my client base isn’t overly aware of what it is until told.

I have been CLS certified for more than 10 years. Initially I received a cash bonus for passing the CLS exam. Many customers are not aware of the significance of STLE certifications, but they can be educated to understand that you have been peer reviewed and your peers believe you know what you’re talking about.

It helped establish credibility on recommendations both from having the certification and the knowledge obtained studying for the certification.

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  ISBN: 978143985379

* MICRO- and NANOSCALE PHENOMENA in TRIBOLOGY
  ISBN: 9781439839225

* HANDBOOK OF HYDRAULIC FLUID TECHNOLOGY
  ISBN: 9781138077348

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Q.2
How did you prepare for your STLE certification exam?

Studied at least 10 hours a week for about four months. Obtaining my CLS was one of the greatest feelings of accomplishment I have ever had.

My company sponsored training for some of our employees trying to certify as OMA I. This training ended up being about 20 hours.

I basically relied on lubrication terminology and definitions to prepare. Past work experience and better understanding of terminology helped me succeed. I was elated to receive my CLS results.

After spending decades in this field and attending many STLE education courses, there was not much more preparation needed!

Worked with a team from Chevron for about nine months and then attended a three-day intensive workshop prior to the CLS exam.

For OMA I, I read The Basic Handbook of Lubrication (Third Edition), plus ASTM D4378 and D6224.

I took the CLS exam in December 1996 and was notified that I passed in January 1997. It was a relief to have passed the exam. I worked for a regional chemical and lubricant distributor at the time, and I did not have a formal training program. My preparation involved reading technical articles for one to two hours, four or five nights a week for six weeks prior to the exam. Before that I had attended Citgo’s Lube School where I was first introduced to STLE and the CLS certification. I had been in the industry for 10 years at the time.

I didn’t really prepare for the CMFS exam because I assumed my years of experience, including numerous STLE courses, prepared me well. I knew the exam would be difficult, and I felt like I had failed. In fact, I passed on my first try and was completely surprised and elated!

The CLS exam was the hardest test I have ever taken. I was extremely happy when I found out I had passed.
CALL FOR PRESENTATIONS

74th STLE Annual Meeting & Exhibition
May 19-23, 2019
Omni Nashville Hotel
Nashville, Tennessee (USA)

STLE’s Annual Meeting & Exhibition is the industry’s most respected venue for technical information, professional development and international networking opportunities. Each year STLE’s conference showcases some 500 technical presentations, application-based case studies, best practice reports and discussion panels on technical or market trends.

Education courses support professional development and prepare qualified individuals for STLE’s three certification programs: Certified Lubrication Specialist™, Oil Monitoring Analyst™ (I&II) and Certified Metalworking Fluids Specialist™. Our annual trade show and popular Commercial Marketing Forum spotlight the latest products and services of interest to lubrication professionals. STLE’s conference is a truly international event, with some 1,600 professionals from around the world attending.

2019 presentations are being sought in the following areas:

- Biotribology
- Condition Monitoring
- Engine & Drivetrain
- Environmentally Friendly Fluids
- Fluid Film Bearings
- Gears
- Grease
- Lubrication Fundamentals
- Materials Tribology (includes Ceramics and Composites)
- Metalworking Fluids
- Nanotribology
- Nonferrous Metals
- Power Generation
- Rolling Element Bearings
- Seals
- Surface Engineering
- Synthetic and Hydraulic Lubricants
- Tribotesting
- Wear
- Wind Turbine Tribology

Abstract Submission
If you are interested in presenting at STLE’s 2019 Annual Meeting & Exhibition, submit a 100-150-word abstract at www.stle.org. Abstracts are due Oct. 1, 2018. Notification of acceptance will be sent in December 2018. While you do not need to prepare a full manuscript to be included on the meeting technical program, you are invited and encouraged to submit a manuscript for review and possible publication in STLE’s peer-reviewed journal, Tribology Transactions.

For more information, please contact:
Merle Hedland • mhedland@stle.org • 630-428-2133

Follow us on YouTube LinkedIn Facebook Twitter #STLE2019
For the CLS exam, I studied various resources for about six months. The exam was difficult, and it took me the entirety of the allotted time to complete it, so it was a great relief when I learned that I had passed. After that I took the OMA I and passed without much preparation at all.

Years of experience, asking questions from other CLS-certified individuals, industry peers and trusted sources. Looking for answers to many questions, therefore learning things I would have never thought important.

I prepared for the exams through years of being in the field with customer interaction and problem solving. I took the CLS before it was a multiple-choice exam and passed on my first take. I was amazed by how many in my employer-sponsored prep class were there for their second and third try. By passing both the CLS and OMA I on my first try, I was very impressed with my grasp of technical expertise based on my peers.

I obtained most of the suggested reference books and used my knowledge and experience. I spent maybe two to three months covering the reference books to help improve my chances. When I received the envelope from STLE, I knew I had passed—it’s like college where the big envelope means success and the little envelop means better luck next time. I was quite happy because the time investment paid off.

Editor’s Note: Sounding Board is based on an informal poll of 15,000 TLT readers. Views expressed are those of the respondents and do not reflect the opinions of the Society of Tribologists and Lubrication Engineers. STLE does not vouch for the technical accuracy of opinions expressed in Sounding Board, nor does inclusion of a comment represent an endorsement of the technology by STLE.
You work in a technical world. Should you belong to a technical society?

Keeping current with technical changes in the lubricants field is a daunting task.

More than 3,000 of your peers have solved this problem by joining the Society of Tribologists and Lubrication Engineers.

STLE is the premier technical organization representing lubrication professionals and tribology researchers. Professionals from industry, academia and government join STLE because they know no organization offers a more complete look at the field of tribology.

STLE provides the lubricant industry’s highest level of technical training and professional development. But the benefits of membership don’t stop there.

STLE membership is a mark of distinction. It confers the seal of authority on you and your organization and affiliates you with the world’s leading experts in lubrication.

You work in a technical world. You belong in a technical society. You belong in STLE.

Learn more about the benefits of STLE membership and how to join at www.stle.org.
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*(Post-convention Issue & Summer Sales Special. Special terms apply.)*

- Ad close: May 25
- Materials: June 1
  - Oil Analysis
  - Aviation Lubricants
  - Bearings
  - STEM

### August
*(Exhibitor Special—Buy an ad, get your 2019 exhibit booth in Nashville, Tenn., free. Special terms apply.)*

- Ad close: June 22
- Materials: June 29
  - Metalworking Fluids
  - Seals
  - Bearings
  - Automotive Tribology

### September
*(TLT 15-year Anniversary Issue.)*

- Ad close: July 25
- Materials: August 1
  - Additives
  - Engine & Drivetrain
  - Oil Analysis
  - Nanotribology

### October
*(Bonus Distribution: ILMA Annual Meeting, Oct. 6-9, Palm Desert, Calif.)*

- (Exhibitor Special—Buy an ad, get your 2019 exhibit booth in Nashville, Tenn., free. Special terms apply.)
- Ad close: August 24
- Materials: August 31
  - Synthetic Lubricants
  - Wear
  - Biocides
  - Automotive Tribology

For information on how to customize a multimedia marketing program that reaches **15,000 lubricant-industry decision-makers**, contact:

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ABOUT THE LEARNING PATHWAYS

STLE has a well-known tradition of providing continuing education to industry professionals ready to take their career to the next level and create value to their employers, customers & peers. Now we’ve expanded our online offerings with the launch of STLE’s Learning Pathways - a reorganization of all STLE content that is more focused, easier to search & accessible in a variety of formats that is right for you. This content is organized to allow individuals to continue developing skills in two major vocational segments: Lubrication Specialists & Oil Analyst.

STLE is a trusted provider of education and a workforce development partner, and the Learning Pathways is just one more valuable information-sharing service STLE offers to benefit industry professionals in their career development.

More products & services to come from STLE Education. Please visit www.stle.org.
Technical Books

Emerging Areas in Bioengineering

Editors: Ho Nam Chang, Sang Yup Lee, Jens Nielsen and Gregory Stephanopoulos
Publisher: Wiley

With more than 40 contributions from expert authors, this is an extensive overview of all important research topics in the field of bioengineering, including metabolic engineering, biotransformations and biomedical applications. Alongside several chapters dealing with biotransformations and biocatalysis, a whole section covers biofuels and biomass utilization. Current perspectives on synthetic biology and metabolic engineering approaches are presented, involving such example organisms as Escherichia coli and Corynebacterium glutamicum, while another section covers topics in biomedical engineering, including drug-delivery systems and biopharmaceuticals. The book concludes with chapters on computer-aided bioprocess engineering and systems biology. This is a part of the Advanced Biotechnology book series, covering all pertinent aspects of the field with each volume prepared by eminent scientists who are experts on the topic in question. Available at www.wiley.com. List Price: $405.00 (USD), hardcover.

Biocomposites: Biomedical and Environmental Applications

Editors: Shakeel Ahmed, Saiqa Ikram, Suvardhan Kanchi and Krishna Bisetty
Publisher: CRC Press

Biomaterials are materials of natural or man-made origin that are used in different fields of science and technology. Biocomposites: Biomedical and Environmental Applications comprehensively covers almost all aspects of biopolymers, natural fibers, algae-based composites, proteins and bionanocomposites, including recent developments, environmental and biomedical applications and biocomposites for chemical and biotechnological modifications, material structures, characterization and processing. These areas have not been covered in a single book before. This book includes recent advances in science and technology in all areas, from chemical synthesis or biosynthesis to end-use applications. It broadens nano- and biocomposite materials’ research and their applications to highlight the recent trends in the field. Part 1 introduces the synthesis and characterization of biocomposites, including natural fibers, resins, etc. Part 2 covers biocomposites such as algae-based composites and proteins and their biomedical and environmental applications. Part 3 covers different bionanocomposites and some of their applications. Available at www.crcpress.com. List Price: $179.95 (USD), hardcover.

STLE Local Section Meeting Calendar

June 2018

STLE Hamilton Section Golf Social, June 1. More information to come. Contact: Mike Deckert or Greg Pottruff, (905) 671-2355.

STLE Philadelphia Section 4th Annual Edward Haney Memorial Golf Outing, June 25, 11:15 a.m. to 7 p.m. Format is four-person best ball with a shotgun start at 12:30 p.m. Social hour and dinner to follow. Sandy Run Country Club, 200 E. Valley Green Rd., Oreland, Pa. Contact phlstiegolfouting@gmail.com.

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

STLE Certification Exams

STLE is offering four certification exams in the coming weeks. Here is the information on each exam:

- May 24 from 9 a.m. to 12 p.m. at the Minneapolis Convention Center, Minneapolis, Minn.
- June 15 from 8-11 a.m. at the Holiday Inn Express Raleigh-Durham Airport, 1014 Airport Blvd., Morrisville, N.C.
- June 22 from 8:30-11:30 a.m. at Lubrication Engineers Inc., 1919 Tulsa St. E, Wichita, Kans.
- June 22 from 9 a.m. to 12 p.m. at Oildoc GmbH, Kerschelweg 29, 83098 Brannenburg, Germany. German language only.

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

Credibility. Respect. Integrity.

Those are the qualities immediately conferred upon you when you attain one of STLE’s technical certifications. Becoming STLE certified not only verifies your technical expertise, it demonstrates your professional dedication to your employer, customers and peers.

STLE offers four technical certifications:

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

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

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

Invest in your greatest asset—you yourself. Plan now to attain your STLE certification.

For more information or to schedule an exam, contact STLE Certification and Section Relations Manager Gina Cairo at gina@stle.org, 847-825-5536.
ICETAT 2018

The International Conference on Engineering Tribology and Applied Technology 2018 (ICETAT 2018) will be held Nov. 16-18 at the Howard Civil Service International House in Taipei, Taiwan. The theme for this year is Engineering Tribology Technology. Topics include basic friction and wear, lubrication, contact mechanics, surface engineering and coating, biotribology and more. For more details on the conference, visit www.tstt.org.tw/icetat2018.

22nd International Conference on Wear of Materials

The 22nd International Conference on Wear of Materials will take place in Miami, Fla., April 14-18, 2019. Organized every two years, the conference provides a unique international forum for researchers and practicing engineers from different disciplines to interact and exchange their latest results. Special sessions will concentrate on engine tribology, wear of tools and tooling materials, friction and wear under vibratory contact, marine applications, role of third bodies during wear and surface texturing for wear reduction. The conference is unique for its paper submission process with full peer review in collaboration with the Elsevier journal, Wear, to ensure technical quality of presentations. Abstracts, which are due May 31, 2018, are now invited on the topics listed on the conference Website at www.wearofmaterialsconference.com.

Freedonia Report: Automotive Lubricant Sales in India to Reach 1.7 Million Metric Tons, Growing 5.5% Annually

Automotive lubricant demand in India is forecast to increase 5.5% annually through 2021 to 1.7 million metric tons, according to a report published by The Freedonia Group, a Cleveland-based industry research firm.

In addition to growth in the country’s light vehicle usage, India’s rapidly expanding motor vehicle production will support demand. The vast majority of motor vehicle lubricant demand will stem from aftermarket applications, which are expected to account for 58% of demand in 2021. Emissions regulations in India are encouraging the use of better quality engines that are more likely to use synthetic lubricants. These and other trends are presented in the study titled Automotive Lubricants Market in India.

The number of motor vehicles in use in India is forecast to expand 8% annually through 2021, nearly the same pace as that seen during the 2011-2016 period. India will see significantly higher growth than the Asia/Pacific region as a whole and higher than the world at large. Although the light vehicle park continues to grow at a rapid rate, two-wheeled vehicles such as motorcycles and scooters still represent a primary means of personal transportation in India. In fact, India surpassed China in 2017 to become the world’s largest market for two-wheeled vehicles.

India is projected to see rapid advances in the demand for synthetic lubricants, as more advanced engine technologies (which are more likely to use synthetic formulations) see greater adoption and more OEMs recommend these products for their ability to help improve fuel efficiency. Growing consumer awareness of the performance advantages of synthetic lubricants also will buoy sales as consumers want to protect what is considered a significant household investment.

Automotive Lubricants Market in India (published February 2018, 87 pages) is available for $2,400 from The Freedonia Group. For details or to arrange an interview with the report’s analyst, contact Corinne Gangloff at (440) 684-9600 or pr@freedoniagroup.com.

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There is still, literally, a lot of mileage to be gained from improvements in lubricants for automobile engines. In particular, as lower and lower viscosities are required to save energy in the hydrodynamic-lubrication regime, the likelihood of engines spending more of their time in the boundary regime increases. This brings with it new challenges, requiring more efficient antiwear and friction-reducing additives. Complicating the picture still further in automobiles is the requirement that traces of any new additive should not poison the downstream catalytic converter.

With these daunting challenges in mind, a collaborative effort led by professors Tobin Marks, Jane Wang and Yip-Wah Chung at Northwestern University, together with colleagues at Argonne National Laboratory and Valvoline, Inc., has been working on developing a new generation of friction-reducing additives, inspired by a molecule used as a friction modifier in the hard-disk industry, known as A20H (see Figure 1).

To lubricate well in the boundary regime, a molecule has to attach strongly to the sliding surfaces. A20H binds well to carbon in the hard-disk surface by means of multiple interactions with the ring atoms. However, for automobile applications, the phosphorus and fluorine content would immediately rule it out, due to its potential poisoning effects on the catalytic converter. Nevertheless, the idea of multiple attachment to a surface by rings can be exploited for the metal-containing surfaces of engines by applying the mechanism of chelation, in which molecules form several bonds to a single metal ion. Thus, the goal was to discover ring-based, chelating, catalyst-compatible, friction-modifying molecules, which could adsorb from the oil onto the sliding surfaces of engines and remain there under relatively high-temperature operating conditions.

After ruling out some molecules that were unstable below 200 C, two candidate structures were chosen, triazines and cyclens (see Figure 2), along with proposed binding interactions with the hydroxyl groups on metal surfaces.

The synthesized triazines and cyclens are stable up to temperatures in excess of 300 C. Tribological tests were therefore performed with base-oil...
solutions of these molecules between steel surfaces under sliding and mixed sliding-rolling conditions, at pressures up to 1 GPa, and temperatures up to 200 C.

The results show that both classes of molecules show friction reduction in the boundary regime at lower temperatures. However, the triazines appear to lose their effectiveness above about 125 C. The cyclen molecules, with attached dodecyl groups (C12-cyclen), however, actually seem to become more effective at higher temperatures, reducing the friction coefficient measured from \( \mu=0.15 \) (base oil) to \( \mu=0.09 \) (base oil + C12-cyclen) at 75 C, and from \( \mu=0.21 \) to \( \mu=0.07 \) at 200 C.

Possibly the most impressive results were obtained during more than one hour of ball-on-flat, reciprocating-sliding tests of steel against steel at 1 GPa pressure and a temperature of 100 C. C18-cyclens (1 wt%) were added to a synthetic base oil (PAO4) and also to a fully formulated 5W30 engine oil (see Figure 3). Their performance was compared to that of Armeen T—a commercially available, alkylamine-based friction modifier—at a similar concentration. In the PAO4 case, the cyclen-containing lubricant showed lower friction compared to both the base oil and the Armeen-T-containing oil after about 1,000 s, whereas in the fully formulated oil, the C18-cyclen-containing 5W30 oil clearly showed a significantly lower friction value than both other lubricants over the entire experiment. This shows that the cyclens are not only of theoretical interest, but their adsorption onto the sliding surfaces can even compete at 100 C with the host of additives already present in commercial oils.

This piece of work is a nice example of a collaboration between, on the one hand, chemists with a thorough understanding of both synthesis and organometallic interactions, and, on the other hand, tribologists who know how to put new additives through their paces under a wide range of realistic conditions.

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

**REFERENCE**

The mileage gap’s upset victor

According to EPA, automatic transmissions are now more fuel efficient than manuals.

By Dr. Edward P. Becker

When I last wrote about the mileage gap between automatic and manual transmissions (December 2014 TLT), that gap was rapidly disappearing. According to the latest report from the U.S. Environmental Protection Agency, the automatic is now the more fuel-efficient choice!

Figure 1 specifically compares the fuel economy of automatic and manual transmission options where both transmissions were available in one model with the same engine. Two contributing factors to this trend are that automatic transmission design has become more efficient (using earlier lockup and other strategies), and the number of gears used in automatic transmissions has increased much quicker than in manual transmissions.

In fact, starting last year the average number of forward gears in U.S. transmissions in cars is about 5.9 for manuals while automatics are averaging 6.3 forward gears with 10-speed transmissions in production and even more forward speeds in development. For example, both Ford and Honda have patented versions of an 11-speed automatic transmission.

Another big change is the mix of manual versus automatic transmission sold in the U.S. Manuals represented about 35% of production in 1980. That share fell to about 7% in 2012 and to 2.2% in 2016. At this rate, it won’t be long before the stick shift joins such automotive relics as the carburetor and the running board.

Among the many contributions of tribologists to the increase in forward speeds is a new generation of automatic transmission fluid (ATF). The Ford designation for the new ATF is Mercon ULV, which stands for ultra-low viscosity. Much like engine oil, reducing the viscosity of transmission fluid reduces the energy loss during flow and in hydrodynamic components. The viscosity of Mercon ULV is roughly half that of traditional ATFs.

Beginning with the 2017 model year, a 10-speed transmission, developed jointly by General Motors and the Ford Motor Co., has been available in the Ford F150 pickup truck and the Chevrolet Camaro. Exactly how much this has improved fuel economy in these vehicles is unclear, but based on published data the improvement is around 4% or about one additional mile per gallon of gasoline for both vehicles.

So by all means enjoy driving a stick if that is your preference. You can still note that a car with a manual transmission costs less than a comparable vehicle with an automatic transmission, a manual transmission is more fun to drive, and manuals are less mechanically complicated than automatics, therefore easier to maintain and less expensive to repair.

Thanks to the automotive tribologist, however, don’t claim that you are doing it for the fuel economy. In fact, starting in the last few years, you are actually wasting fuel!

Ed Becker is an STLE Fellow and past president. He is president of Friction & Wear Solutions, LLC, in Brighton, Mich., and can be reached through his website at www.frictionandwearsolutions.com.
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