# October 2015 Highlights

## ORNL Fuels, Engines, and Emissions Research Center

### TECHNICAL HIGHLIGHTS

**Journal Paper to Report the Oak Ridge National Laboratory's (ORNLs) Recent Discovery of Incompatibility between Diamond-Like Carbon (DLC) and Zinc Dithiophosphate (ZDDP)**

Y. Zhou, D. N. Leonard, H. M. Meyer, H. Luo, and J. Qu, "Does the Use of Diamond-Like Carbon Coating and Organophosphate Lubricant Additive Together Cause Excessive Tribochemical Material Removal?" in *Advanced Materials Interfaces*, 2015, DOI: 10.1002/admi.201500213. An unexpected but interesting observation at an interface between steel and DLC in the presence of phosphate-based lubricant additives was recently discovered at ORNL. DLC coatings have demonstrated excellent tribological and mechanical properties with great potential in many industrial applications. Phosphate additives, such as conventional ZDDP and newly developed ionic liquids, are known to be very effective in wear protection of steel bearing surfaces. One natural question is what happens when DLC coatings are used together with anti-wear additives? In this study, we discovered significantly increased wear rate on a steel surface that rubbed against DLC when and only when lubricated by phosphate-based anti-wear additives. Very limited literature (only two papers) had touched base with this detrimental effect with an unproved hypothesis that a competition existed between ZDDP-produced tribofilm and DLC-induced carbon transfer. Our experimental results however are clearly contradictory to the literature hypothesis and we instead propose a new mechanism for such excessive material removal based on carbon-catalyzed chemomechanical interactions, which is supported by surface characterization. Such interfacial phenomena is important not only for fundamental understanding but also for technology implementation.

**The Fuels, Engines, and Emissions Research Center (FEERC) Holds Summer Student Research Symposium**

On August 5, 2015, six of FEERC's summer researchers presented brief, summary presentations of their completed work, as well as the future outlook for the projects that will continue under their FEERC mentors. This was a great opportunity for the science and engineering students to succinctly describe their work to our fuels, engines, and emissions-focused audience and thereby understand their research more clearly. What's more, it was a worthwhile chance for the early, mid-, and advanced ORNL-FEERC research professionals to hear about the exciting perspective our student researchers bring to the innovation table. This is the fourth year in a row that FEERC has hosted a dedicated summer student research symposium.

***Mechanical Engineering Magazine* mentions an ORNL Lube Oil Project**

An article in the September 2015 issue of *Mechanical Engineering Magazine* mentions the work of several national laboratories (including ORNL) in the area of lubricant technologies. ORNL is mentioned as a contributor on a collaborative project with Pacific Northwest National Laboratory (PNNL). The project was awarded two years ago through a competitive Funding Opportunity Announcement by the Department of Energy (DOE). PNNL is developing a new oil additive to enable increases in engine efficiency through friction reduction. ORNL's FEERC and High Temperture Materials Laboratory are supporting the project with fundamental friction measurements and


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demonstration of the fuel efficiency benefit of candidate lubricants in modern engines. ORNL's Scott Sluder and Jun Qu were interviewed for the article.

**ORNL Compatibility Study Reveals Dimethyl Ether (DME) to be Highly Compatible with Many Existing Fuel Components**

A solubility analysis was performed for DME (and its blends with diesel) to assess its compatibility with elastomers and plastics used in fuel storage and delivery systems. Of the elastomer materials, silicone, neoprene, and polyurethane exhibited similar solubility values for both diesel and DME (and blends of each). Interestingly acrylonitrile butadiene rubber (NBR), which is a common seal and fuel hose material, showed pronounced improvement in compatibility with DME content, especially for concentrations exceeding 20%, and in fact, neat DME can be expected to produce only modest swelling in these materials. In contrast, fluorocarbons (which have replaced NBR seals in systems exposed to E10 and E85) were shown to be less compatible in DME. These findings are important because they show that high cost fluorocarbons are less compatible than low cost NBRs when exposed to DME and its blends with diesel. Results for the plastic materials show that for many plastics the compatibility improves with DME content (compared to neat diesel fuel). Notable exceptions include high density polyethylene, polypropylene, and PTFE. PTFE (or Teflon) is a common high performance plastic material and its use may need to be precluded for use with DME and its blends with diesel fuel. The analysis indicates that DME should be highly compatible in existing engines and fuel dispensing infrastructure.

## HIGH-LEVEL OR NOTEWORTHY VISITS

## INVITED TALKS AND PRESENTATIONS

**FEERC Neutron Research Highlighted at American Society of Nondestructive Testing Annual Meeting**

Charles Finney gave an invited presentation at the American Society of Nondestructive Testing Annual Meeting in Salt Lake City. The talk highlighted the multi-year work by FEERC on neutron imaging and analysis of automotive fuel injectors and particulate filters in collaboration with ORNL neutron scientists and industrial and academic partners.

**FEERC Staff Member Delivered Keynote Address at Recent Association for Unmanned Vehicle Systems International (AUVSI) Workshop**

Mike Kass gave the keynote address to the AUVSI workshop on Unmanned Aerial System (UAS) Propulsion: Optimization, Technical Challenges and Future Directions held on October 14 in Washington, DC. This workshop was the first ever devoted to the issues associated with unmanned aerial propulsion systems and included leaders from industry, academia, and government agencies. The AUVSI is the World's largest professional society devoted exclusively to advancing the unmanned systems and robotics community. During the workshop, Brian Wynne (president of AUVSI) formally asked the workshop committee to organize a similar technical session at the annual AUVSI XPONENTIAL meeting next May.

## AWARDS

**ORNL and Cummins Team Recognized as "Researcher(s) of the Year" at 2015 Biodiesel Technical Workshop**

Michael Lance from the Material Science and Technology (MS&T) Division was awarded the Biodiesel Researcher of the Year Award by the National Biodiesel Board, which represents more than 200 biodiesel producers and acts as a liaison between producers and original equipment manufacturers (OEMs). The award was given in recognition of Michael's research conducted in collaboration with FEERC researcher Todd Toops and MS&T researcher Andy Wereszczak and Cummins, Inc. on sodium metal impurities in biodiesel. These impurities were thought to have an impact on diesel catalyst system performance and durability. Michael's study found that sodium had little impact on the catalytic functionality and that lube-oil phosphorous was the primary deactivation source. The research was funded by the DOE Vehicle Technologies Office's Propulsion Materials program.

**ORNL Significant Event Award (SEA) for "Discovery and Fundamental Understanding of Incompatibility between Diamond-Like-Carbon Coatings and Lubricant Additives provide New Insights for Future Materials Development"**

A team of staff members, Yan Zhou, Donovan Leonard, Harry Meyer, Huimin Luo, and Jun Qu, received an ORNL SEA for discovering an unexpected and important phenomenon at the interface between diamond-like carbon (DLC) coatings and steel in the presence of phosphate-based lubricant additives. DLC coatings have demonstrated excellent low-friction and anti-wear properties with great potential in various transportation and industrial applications, including heavy-duty diesel engines. Phosphate additives, such as conventional zinc dialkyldithiophosphates (ZDDPs) and ORNL-developed new phosphonium-organophosphate ionic liquids, are known to be very effective in wear protection of ferrous alloy bearing surfaces. However, in 2014–2015, the ORNL team discovered a significantly increased wear rate (by 2–4X) on the steel surface that rubbed against DLC coatings when and only when phosphate anti-wear additives are used in the lubricant. Such detrimental effects do not apply to noncarbon coatings or nonphosphate additives. Based on comprehensive surface characterization, a new wear mechanism has been proposed to explain the excessive material removal: DLC-catalyzed rapid tribochemical reactions between the phosphate additive on the steel surface. Detailed results are presented in a new journal paper in *Advanced Materials Interfaces* (DOI: 10.1002/admi.201500213). The fundamental understanding of the incompatibility between DLC coatings and phosphate-based lubricant additives has significant implications and provides new insights for future development and implementation of advanced bearing materials and coatings as well as new lubricant additives and lubricant formulations. The success of this study exemplifies the power of multi-disciplinary research across groups and divisions, in this case by bringing together ORNL's unique combination of expertise and facilities in chemical synthesis, tribological analysis, and material characterization.

## OUTREACH