Tuesday, May 19, 2009

Registration: 6:30 am – 5 pm – Foyer/Laredo 2
Speakers Breakfast: 7 – 8 am – Fiesta 6

Committee Meetings
Corporate Member Business Meeting
7 – 8 am – Fiesta 2
Editorial & Publication Advisory Board
8 – 10 am – Fiesta 1
Education Course Chairman
10 – 11 am – Fiesta 2
Education General Committee
2 – 3 pm – Fiesta 2
Fellows Committee
3:30 – 5 pm – Fiesta 2
Awards Committee
5 – 7 pm – Fiesta 1
Non-Ferrous Pre-Planning Meeting
5 – 6:30 pm – Sonoma B
Metalworking Fluids Education Certificate
Subcommittee
5:30 – 6:30 pm – Fiesta 2
Emerging Technologies Committee
6 – 8 pm – Sierra Room
ASME Tribology Division Executive Committee
7 – 9 pm – Fiesta 1

Technical Committee Meetings
Engine & Drivetrain
4:30 – 5 pm – Coronado D
Metalworking
5 – 5:30 pm – Fiesta 3/4
 Nanotribology
5 – 5:30 pm – Yucatan 1
Lubrication Fundamentals
5:30 – 6 pm – Coronado F/G
Synthetic Lubricants
5:30 – 6 pm – Coronado A
Environmentally Friendly Fluids
5:30 – 6 pm – Fiesta 7/8
Solid Lubricants
6 – 6:30 pm – Yucatan 2

Commercial Exhibits and Student Posters
9:30 am – 5:30 pm – Veracruz C

Technical Sessions (8 am – Noon)
3A Hydraulic Fluids – Coronado A
3B Wear I: Panel Discussion “The Impact of Fuel Economy and Emissions Regulations on Wear of Engines and Drivetrains” – Coronado B
3C Condition Monitoring I: Mini Course and Papers: Mobile Oil Analysis Labs – Coronado C
3D Engine & Drivetrain III: Friction & Fuel Economy – Coronado D
3E Fluid Film Bearings III: Gas Bearings – Coronado E
3F Lubrication Fundamentals III – Coronado F/G
3G Metalworking I – Fiesta 3/4
3H Commercial Marketing Forum III – Fiesta 5
3I Environmentally Friendly Fluids – Fiesta 7/8
3J Nanotribology III: Nanoparticle Research – Yucatan 1
3K Special Session on Coatings II – Yucatan 2

President’s Luncheon/Business Meeting:
Noon – 2 pm – Coronado H/J

Technical Sessions (2– 6 pm)
4A Synthetic Lubricants – Coronado A
4B Wear II – Coronado B
4C Condition Monitoring II – Coronado C
4D Engine & Drivetrain IV: Fuel Impact – Coronado D
4E Fluid Film Bearings IV: Modeling – Coronado E
4F Lubrication Fundamentals IV – Coronado F/G
4G Metalworking II – Fiesta 3/4
4H Commercial Marketing Forum IV – Fiesta 5
4I Environmentally Friendly Fluids – Fiesta 7/8
4J Nanotribology IV: Carbon-based Materials (HOPG, CNT, DLC) – Yucatan 1
4K Special Session on Coatings III – Yucatan 2
4L Solid Lubricants (starts at 3:30 pm) – Yucatan 2

Exhibit Hours
Hours for the 2009 STLE trade show in Veracruz C are:

Monday: Noon – 5 pm
Tuesday: 9:30 am – Noon & 2 – 5:30 pm
Wednesday: 9:30 am – Noon
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<td>Shear and Wear of Hydraulic Fluids Using Star and Linear PMA Viscosity Modifiers, B. Schober, p.70</td>
<td>Shear and Wear of MRP and Wear: The Morphological and Mechanical Properties of Surfaces Exposed to Sooted Lubricants, D. Yablon, p.72</td>
<td>“Site-Direct” Oil Analysis Completes the Condition Monitoring of Industrial Machine Monitoring, J. Poley, p.74</td>
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<td>Solution of Tribological Problems on a Compact Distribution Steam Valve for Capacity Type Expansion Machines of Rankine Cycle for an Automobile, M., Kenji. p. 104</td>
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**TUESDAY**
**HYDRAULIC FLUIDS**

**Session Chair:** L. Rudnick, Ultrachem, Inc, New Castle, DE  
**Session Vice Chair:** J. Sherman, BASF, Wyandotte, MI

**9 – 9:30 am**  
**A Fluid Solution to Preventing Varnish Formation in Hydraulic Systems**  
B. Filippini, R. Profilet, A. Barber, The Lubrizol Corp., Wickliffe, OH

Varnish is well known to compromise the performance and efficiency of hydraulic systems. Varnish can plug filters and cause valves with fine clearances to stick, causing unplanned downtime. The replacement or cleaning of servo valves and other internal components coated with varnish can add significant cost to a hydraulic operation. Preventing varnish will have a significant impact on the operation of hydraulic systems, and a hydraulic fluid that is resistant to varnish formation can provide value to end-users. Until the introduction of Group II base oils, most hydraulic fluids were formulated using Group I base stock. Recent years have seen the price gap between Group I and Group II decrease significantly. Group II base oils are used more commonly now than in the past, especially for high-tier fluids in part due to their ability to enhance oxidation life. Fluids using Group II oil could have a different propensity to varnish formation than those containing Group I base oil. Formulations containing Group II oils might produce less varnish due to their inherent oxidative stability versus Group I base oil, or they could make varnish worse as they will be a poorer solvent to the polar precursors to varnish. Regardless, any fluid solution to varnish should be applicable across a range of base oils. This paper will give background on varnish and discusses recent developments in fluid technologies designed to prevent varnish formation for hydraulic hardware. Key testing and the impact of the additives will also be presented.

**9:30 – 10 am**  
**Impact of Fresh and Sheared Oil Viscosity Requirements on the Formulation of Hydraulic Fluids**  

For many years hydraulic oils were characterized using the ISO 3448 viscosity classification. Developed in the mid-seventies, it defined a finite number of discontinuous grades based on a minimum and maximum viscosity at 40°C. In 1997, efforts by ASTM resulted in the ASTM D 6080 classification that included several viscosity requirements on the fresh and sheared oil. More recently, two new sets of viscosity and VI limits on the fresh and sheared oil were proposed to provide improved efficiency compared to conventional HM oils. These are the Maximum Efficiency Hydraulic Fluid definition (MEHF) and the NFPA guidelines for hydraulic fluid viscosity selection. Any addition to the ISO grade definition introduces new constraints on both the kinematic viscosity and VI of the formulation. Using a large number of blends based on VI Improvers having different shear stability level, we investigated the impact of the viscosity constraints included in the MEHF and NFPA guidelines on the formulation windows of the most common ISO grades. The degree to which the guidelines overlap, the so-called “formulation windows” was found to depend on the ISO grade and shear stability of the VI Improver considered. This work provides a framework for an improved ability to select formulation targets considering these new guidelines.

**10 – 10:30 am ♻ Break**

**10:30 – 11 am**  
**Shear and Wear of Hydraulic Fluids Using Star and Linear PMA Viscosity Modifiers**  
B. Schober, B. Filippini, Lubrizol Corp., Wickliffe, OH

Poly(methacrylate) (PMA) viscosity index improvers (VI) offer many advantages in hydraulic formulations. Of recent interest is the boost they can give to the viscosity index (VI) of these fluids. High VI fluids have been linked to improved fuel efficiency. This improvement in fuel/work efficiency has spawned growth in the multigrade hydraulic fluid market. The basic fundamentals of formulating hydraulic fluids with Linear PMAs has been well understood. But now a new parameter has been revealed: polymer architecture. This study shows that architecture fundamentally changes the thickening per shear relationship. With Star PMAs it is possible to obtain the same blend viscometrics with improved shear stability over Linear PMAs. It is also possible to create blends with higher VI but the same shear stability. In light of
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the benefits of high VI toward fuel efficiency, this is an important advance. The Star PMAs also help extended shear stability. This can be translated into longer fluid life. Reduction of shear loss is expected to help maintain the fuel efficiency throughout the life of the fluid and retain lubrication, protecting against pump wear. In this work we show that formulations with Star PMA appeared to have improved wear protection above formulations with Linear PMA.

11 – 11:30 am
Hydraulic Efficiency Development

F. Herrero, Lubrizol, Ltd., Hazelwood, United Kingdom, B. Schober, Lubrizol Corp., Wickliffe, OH

Improving the efficiency of hydraulic systems is an ever increasing desire of system designers, equipment manufacturers and end users. This presentation will describe test results relating to the efficiency of a series of tests of test fluids. For the initial study, the Denison Hybrid Pump which contains both vane pump and piston pump was utilized. In the testing, the hybrid pump system alternates pressure from high to low with both piston and vane pump, as per the Denison HF-0 Procedure TP-30560. The testing conditions are representative of real field conditions for off-road equipment. Test fluids evaluated include various viscosities from ISO VG 32 to ISO VG 68 monograde fluids. The efficiency of multigrade fluids is also examined. These are blended with traditional viscosity modifiers as well as the latest Lubrizol technology. The optimum viscosity for efficient hydraulic fluids at various operating temperatures will be determined.

WEAR I

Session 3B  Coronado B

PANEL DISCUSSION

8 – 10 am
“The Impact of Fuel Economy and Emissions Regulations on Wear of Engines and Drivetrains”

Session Chair: D. Eberle, Southwest Research Institute, San Antonio, TX
Session Vice Chair: P. Wang, The University of Toledo, Toledo, OH
Panel: Victor W. Wong, PhD, MIT, Cambridge, MA
  Ardian Morina, PhD, University of Leeds, Leeds, United Kingdom
  Vasu Bala, PhD, Cognis Corp., Cincinnati, OH

10 – 10:30 am  Break

10:30 – 11 am
Nanoscale Insights into the Mechanism of Soot-Induced Wear: Mechanical and Topographical Properties of Surfaces Exposed to Sooted Lubricants

D. Yablon, P. Jacobs, P. Kalamaras, M. Webster, ExxonMobil Research and Engineering, Annandale, NJ

Soot, a common by-product of diesel engines, is a nanometer-sized carbonaceous material that impacts engine oil performance in many ways including increased wear in engine parts such as valve train, cams, and piston rings. The mechanism behind soot-induced wear is poorly understood though various theories have been suggested including abrasive wear, depletion of antiwear additive, and contact starvation. With scanning probe microscopy (SPM), we have explored the nanoscale properties of metal surfaces exposed to sooted, fully-formulated lubricants in a reciprocating ball-on-flat tribology, specifically examining the topographical and nanomechanical surface properties. We include results for both real engine soot and soot surrogate in the form of carbon black. In the tribological configuration in our test, soot acts as an abrasive that rubs away the boundary lubrication film revealing the native steel substrate on a timescale of the order of minutes. The resulting surfaces reveal nanometer-sized grooves in the direction of rubbing, a surface topography in marked difference to those exposed to unsooted, fully formulated oils where a thick (tens of nm) boundary film with pitted morphology is formed.
11 – 11:30 am
Advances in Modern Wear Measurement for Correlation of Model Tribometer Systems to Realistic Applications

M. Jech, T. Wopelka, J. Hasnain, F. Franek, Austrian Center of Competence for Tribology, Wiener Neustadt, Austria

For wear investigations of engine assemblies, such as piston ring and cylinder liner systems, in a model tribometer test realistic loading conditions should be used and the validity of the simplifications for the model test proved. Hence, the area of contact is in the focus as it is the key for the calculation of the contact pressure from the applied load and the wear height from the wear volume measurement. With this calculation the obtained values can be used for correlating the model tests to engines. In this paper the fundamentals of a wear measuring technique applying radioactive isotopes, the methods of correlating the contact area of the model to realistic applications, and the final results of wear measurement are illustrated. Main focus is laid on the investigation of running in and constant wear behaviour of CrMoV-steel piston rings and AlSi-cylinder liner due to loading conditions.

11:30 – Noon
Wear Analysis of Automobile Clutch Plates – A High Resolution Microscopic Approach

A. Basu, A. Pandey, V. Choudhary, Indian School of Mines University, Dhanbad, India

The automobile industries are geared to enhance the production target commensurate with the rapid industrial development in India. The clutches are the essential components used in vehicles for the purpose of ensuring operational flexibility as well as safety of the transmission system. The surface characteristics of clutch plates would be examined keeping in view the material property to understand its wear behaviour. This paper has aimed to analyze the wear of clutch plates using SEM and profilometry. The study covers wear analysis of clutch plates of two wheelers and four wheelers. A detailed morphological analysis would be carried out to study the rejected clutch components for wear, crack growth, fracture, pile-ups etc. A theoretical study is also aimed to look into the aspect of thermal effects that is likely to develop in clutch operation. Based on the basic analogy of mechanical wear followed by SEM based examination, a comparative study of different designs of clutches for the above vehicles would be done in this regard. As an extension of this exercise, the materials used for the construction of these clutch plates would also be examined using EDAX technique. It is intended to have an in-depth look into the aspects of mechanical wear and its influence in relation to the type of material and its composition used in the manufacturing of this component. Hopefully, this study would highlight the critical aspects of wear of material of these components so that it can provide some feedback to the automobile design engineers as well as to the users of the vehicles.

MINI COURSE AND PAPERS: MOBILE OIL ANALYSIS LABS

Session Chair: C. Chichester, Dow Corning Corp., Midland, MI

Mobile Fluid Condition Monitoring Laboratories opens with 30 minutes on pros and cons of commercial versus in-house laboratories, at-line and on-line testing, and mobile laboratories from an end-user perspective. Selection of the preferable testing approach will include analysis of the equipment types, requirements for equipment safety, availability & reliability, required test types, test interpretation issues, failure progression rates and how all relate to the Predictive Maintenance process. The session will then move outside to the Mobile Lab where several options for outfitting a mobile laboratory are presented. This hands-on instrument tour explains which ASTM and/or ISO methods can currently be performed in a mobile environment to allow rapid machinery condition assessment.

8 – 8:30 am
Pros and Cons of Commercial Labs, In-house Testing, at Line Tests, and Mobile Labs

G. Staniewski, Ontario Power Generation, Pickering, ON, Canada

Predictive Maintenance is the preferable maintenance strategy in a typical modern production facility. It usually utilizes Vibration Monitoring, IR Thermography, Oil Analysis, Motor Diagnostics and Ultrasound technologies. Among these technologies Oil Analysis usually creates the greatest implementation problems for end users. Of concern is the selection of the preferable approach for oil testing. Oil tests can be carried out in a commercial lab, performed in-house or in
Technical Sessions

Sessions 3C-3D

mobile labs. There is also an increasing trend of monitoring oil condition using specific sensors installed directly on equipment. This paper will discuss the pros and cons of all four approaches for oil analysis from the end user’s perspective. Selection of the preferable testing approach will include analysis of the equipment types, requirements for equipment safety, availability and reliability, required test types and failure progression rates. Quality of sampling, testing accuracy, personnel qualification, test result interpretation, reporting and storing processes will also be discussed. Finally, comments will be provided on how each of the oil analysis approaches would support the Predictive Maintenance program.

8:30 – 10 am
Mobile Fluid Condition Monitoring Laboratory: The Future of Modern Industrial Maintenance Practices
J. Duchowski, HYDAC Technology Corp., Sulzbach, Germany
Rapid and accurate assessment of fluid condition can often be of paramount importance in ensuring reliable equipment operation in modern industrial environments. Equipment operators increasingly demand shorter turn around times from industrial laboratories in order to make informed decisions about corrective actions to be carried out, should the evaluation results so indicate. Should doubt arise in regard to the obtained data and require repetition of procedures, additional time delay might result in detrimental impact on system components and/or fluid condition. A convenient way to overcome these difficulties is through employment of mobile laboratories equipped with analytical instruments mirroring those found in off-site facilities as closely as possible. This mini-course will present several options for outfitting a mobile laboratory, provide a guided, hands-on tour of the instruments installed and explain which ASTM and/or ISO methods can currently be performed to provide fluid and system assessment expected to be found in a standard laboratory assay.

10 – 10:30 am  ❌ Break

10:30 – 11 am
“Site-Direct” Oil Analysis Completes the Condition Monitoring Goal of Continuous Machine Monitoring
J. Poley, CMI, Miami, FL
The advent of oil circuit sensors beyond pressure and temperature has elevated Oil Analysis into a real time event, allowing this invaluable process to take its place alongside Vibration Analysis, long a real time tool for machinery condition monitoring. Oil condition and particle-monitoring sensors were heretofore not viable because they weren’t technically effective, nor were they dependable in rugged conditions. Earlier attempts to manufacture sensors for oil condition assessment met with repeated failure, as technology had not been fully developed. In the early 21st century we are now seeing products coming forth that finally meet the promise of a holistic CM program, where “CM” can also stand for “Continuous Monitoring”, opening significant pathways to greater value from Condition Monitoring programs than ever before.

11 – 11:30 am
Novel Corrosion Sensor Based on Capacitive Coupled Electrodes for the Determination of Oil Corrosiveness
C. Schneidhofer, N. Doerr, AC2T research GmbH, Wiener Neustadt, Austria, B. Jakoby, Johannes Kepler University Linz, Linz, Austria
Oil acidification is a crucial parameter requiring continuous oil condition monitoring. Special attention is paid to oil acidification in the case of engines driven with biofuels. Here, acidification is the main reason for oil changes. Therefore, a corrosion sensor has been proposed using material loss of a metal film due to corrosion. Previous concepts were based on the monitoring of the electrical resistance. Substantial improvements of the corrosion sensor now allow the simultaneous identification of different corrosion mechanisms – in detail quasi-uniform corrosion and corrosion in blotches or spots. The improved concept is based on capacitive coupled electrodes combined with special electronic measuring equipment. Experiments carried out in the laboratory comprised the immersion of the sensor in model oils characterised by different amount and type of acidic components as wells as used oils samples from engines. These experiments clearly showed a correlation to the acidification expressed by TAN or i-pH. Further, adequate reproducibility underlines the potential for online oil condition monitoring.
11:30 – Noon
Performance of FTIR and Chemometrics for Oil Condition Monitoring of Gas Engine Oils
A. Graff, N. Doerr, AC2T research GmbH, Wiener Neustadt, Austria

In stationary gas engines fuelled by biogas, acidification often turns out as the drain interval determining parameter. In many cases, chemometric data processing based on infrared spectrometry allows a rapid prediction of acidification, e.g. expressed as acid number, with low effort necessary. Chemometric modeling comprised principal component analysis (PCA) for qualitative evaluation and partial least squares regression (PLS) for quantitative evaluation of gas engine oils ageing. Usually, chemometric models are applied to a limited number of type of oil and fuel gas compositions as well as gas engines. The performance of such models has been evaluated by the extension of chemometric prediction of acidification parameters to different types and different engines. The findings showed that fuel gas quality was a crucial factor in engine oil degradation. Further, the results from field tests have been compared with those from oil samples generated by a special artificial ageing device. Thereby, knowledge on fuel type specific ageing mechanisms of different gas engine oils has been gained.

ENGINE & DRIVETRAIN III
Session 3D * Coronado D

FRICTION & FUEL ECONOMY

Session Chair: P. Lee, University of Leeds, Leeds, United Kingdom

8:30 – 9 am
Development of Fuel Efficient Lubricants as Measured by the Sequence VID Engine Test
T. Miller, A. Boffa, J. Martinez, J. Wang, Oronite, Richmond, CA

The desire for improved fuel economy is a global phenomenon. In the U.S. the fuel economy requirements are regulated through the use of Corporate Average Fuel Economy (CAFE) limits. In 2007, the Energy Independence and Security Act included a provision in which the CAFE will be increased from the current 27 miles per gallon (MPG) to 35 MPG by 2020. In addition, California has proposed CO2 legislation that will phase-in earlier and effectively lead to higher fuel economy standards in that state. The mandates are forcing engine builders to look at many areas to improve fuel economy. The engine lubricant's impact on fuel economy, while small, is one of those areas. The Sequence VID fuel economy test which will be included in ILSAC GF-5 has been designed to correlate with performance in the Federal Test Procedure (FTP) that is used to determine CAFE. Consequently, proper understanding of the Sequence VID appetite will allow for the development of engine lubricants that yield real world fuel economy improvement. In this paper, we will explore additive chemistry effects on fuel economy as measured by the Sequence VID engine test. All stages of the VID will be analyzed individually to understand how formulation changes can affect fuel economy in boundary, mixed, and hydrodynamic lubrication. Also discussed is the assessment of different friction and viscometric bench tests and these tests's ability to predict Sequence VID results. The development of a simple model for VID prediction follows this discussion.

9 – 9:30 am
Measuring the Friction and Film Thickness in Real Journal Bearings
R. Baker, C. Hamer, PCS Instruments, London, United Kingdom

Crankshaft main and big end bearings operate over a wide temperature range from ambient up to approximately 150°C and under extreme cyclical loads. Average individual loads are normally of the order 1 – 10 KN, but these loads may rise to 40 KN over the first few degrees of the power stroke. The transient nature of this loading cycle is critical in simulating the operation of journal bearings. A computer controlled journal bearing test machine for the measurement of bearing friction over a wide range of operating conditions has been developed. This machine has been designed to accommodate real journal bearings and to accurately simulate the dynamic operating conditions experienced by those bearings in commercial gasoline and diesel engines and has the added capability of being able to measure the film thickness during the test cycle. Results presented show the effect of additives on film thickness and friction under real engine conditions.
Technical Sessions

Session 3D

9:30 – 10 am
Liner Surface Improvements for Low Friction Piston Ring Pack
C. Anderberg, Powertrain, Göteborg, Sweden, F. Cabanettes, Z. Dimkovski, B. Rosén, Halmstad University, Halmstad, Sweden

The demands on decreased environmental impact from vehicles are resulting in a strong push for decreased engine oil and fuel consumption. Engine oil and fuel consumption are to a great extend controlled by the topography of the drive line components such as cylinder liners, piston rings, cam shafts, followers, gear surfaces and others. The tribological considerations in the contact between the piston ring and cylinder liner have attracted much attention over several decades. Many non-conventional cylinder liner finishes has been and are being developed with the aim to reduce oil- and fuel consumption, but the effects of surface finish on piston ring pack performance is not well understood. One way of reducing friction in the cylinder system is to reduce tangential load from the piston ring pack, mainly the oil control ring but with the unwanted effect of increased oil consumption and blow by. To maintain the oil consumption level for the cylinder system improved cylinder liner surfaces was developed and tested.

One solution for liners surface is change in honing angle. Calculations with simulation software showed that a lower honing angle helps build hydrodynamic pressure at lower speeds and loads. Also a non plateau surface is tested. To improve understanding of the result the measured surfaces were evaluated in elastic and elasto-plastic rough contact models. The outputs of the model are microscopic pressures as well as deformation modes. Further, standard roughness parameters were computed to connect to outcome from the modelling.

10 – 10:30 am ✴ Break

10:30 – 11 am
Ionic Liquids as Possible Additives for Drivetrain Fluids
M. Fox, University of Leeds, Leeds, United Kingdom

Ionic liquids are increasingly studied for their positive tribological effects between steel/steel, steel/aluminium and metal/plastic contacts. It is timely to consider these compounds as useful additives in drivetrain fluids. Whilst ionic liquids are extraordinarily expensive, as low level, ~1%, additives in hydrocarbon fluids and greases, they show considerable reductions in friction coefficients and wear. It is demonstrated that ionic liquid additives of the imidazolium cation group, plus other nitrogen heterocycles, give considerable increases in FourBall test weld load for both base and fully formulated greases. The anions may be fluorinated or non-fluorinated, the latter group giving only a slight decrement in performance. Strong synergy exists between ionic liquids and other compounds, e.g., tritolyl phosphate or carboxylic acids, etc., in reducing friction coefficients and wear. Possible applications in drivetrain lubrication are discussed for investigation.

11 – 11:30 am
Property-Blending Relationships and Tribological Behavior of Ionized Vegetable Oils in Lubricant Formulations
B. Zhmud, M. Roegiers, E-ION s.a., Brussels, Belgium

Broad commercialization of hydrorefining technologies in the past few decades has created an abundant supply of API Group II and III base oils. Despite many undisputed advantages over their Group I predecessors, these new base oils have one major drawback – they lack solvency and lubricity. This fact, in view of an increased emphasis on fuel economy, is a major driver of market growth for lubricity and solubility improvers. The present paper describes the unique properties of a special class of such additives – ionized vegetable oils. These additives are used in formulations of fuel-economy engine oils and gear lubricants. A specific emphasis is placed on the viscosity-blending relationships, solubility, seal compatibility, oxidation stability and tribological performance of binary blends of ionized vegetable oils with mineral oils.

It is shown that: (i) ionized vegetable oils can be used as solubility and lubricity improvers for Group II-IV basestocks; (ii) ionized vegetable oils have good seal compatibility in combination with various mineral base oils; (iii) ionized vegetable oils stabilize mineral bases against oxidation and have excellent antisudge efficiency; (iv) ionized vegetable oils are potent friction modifiers which improve lubricity and reduce friction and wear, acting synergetically with common EP additives. Unlike EP additives, which act when a direct asperity-asperity contact occurs in the boundary lubrication regime, ionized vegetable oils function by extending the range of operational conditions under which the film lubrication regime is sustained.
physical properties and performance characteristics of fuels, lubricants and materials
FLUID FILM BEARINGS III – GAS BEARINGS

Session Chair: I. Santos, Technical University of Denmark, Lyngby, Denmark

8 – 8:30 am

Developments in the Modeling of Compliant Foundation Foil Gas Bearings

R. Bruckner, NASA, Glenn Research Center, Brookpark, OH

NASA and the Army have a vested interest in advancing the analysis capabilities of Gas Foil Bearings for use in propulsion systems. Small, high-speed, lightly-loaded turbomachinery offers a class of applications with demands well-matched to the performance capabilities of Gas Foil Bearings. Examples of NASA and Army applications of interest include: Optimized Rotorcraft Propulsion, general aviation propulsion, regional jet propulsion, turbo-generators, turbo-compressors, and rocket turbo-pumps. Successful machines utilizing gas foil bearing technology demonstrate that the technology is feasible for turbomachinery of this size class. Design of such systems, however, is currently more of an art than a science because of a lack of accurate computational design tools and procedures. NASA and the Army have, and continue to support efforts to develop the tools and procedures necessary to design using minimal hardware and experimentation iterations. It is believed that more success stories and better design tools will make gas foil bearing use more prolific and less costly to implement. Several efforts are underway to raise the state of the art of foil bearing modeling. Predictive capabilities for these bearings must be enhanced in order for high speed turbomachinery manufacturers to assess their application prior to fabrication. This is currently not the state of the art. Advancements in modeling along with ties to experimental data and code validation will be presented.

8:30 – 9 am

Design of a High-Speed, Oil-free Bearing Test Rig

M. Conlon, A. Dadouche, W. Dmochowski, R. Payette, B. Liko, J. Bedard, National Research Council Canada, Ottawa, ON, Canada

Oil-free foil bearings are self-acting, compliant-surface hydrodynamic bearings that use air as their lubricant. This paper presents details of a unique experimental facility dedicated to measuring both the steady-state and dynamic properties of foil bearings under a variety of (controlled) operating conditions. The bearing under test is placed at the midspan of a horizontal, simply-supported, stepped shaft which rotates at up to 60krpm. Static and dynamic loads of up to 3500N and 450N (respectively) can be applied by means of a pneumatic cylinder and two orthogonal electrodynamic transducers. The bearing housing is instrumented with two single-axis accelerometers (orthogonal to each other) and eight proximity probes (arranged in orthogonal pairs at the axial extents of the bearing housing), as well as numerous thermocouples. In the steady-state test configuration, an aerostatic bearing is used to apply a static load to the bearing under test and a torque arm measures the viscous drag on the bearing. The dynamic test configuration connects each electrodynamic transducer to the bearing housing through a stinger and flexure assembly, which ensures that the bearing housing is unconstrained in directions perpendicular to the shaking force. Force transducers measure the applied static load and the applied dynamic load in all cases. The steady-state test configuration permits high-fidelity measurement of load capacity and viscous drag, while the dynamic test configuration is used to assess bearing stiffness and damping coefficients.

9 – 9:30 am

Experimental Analysis of Circular Air Bearing Dynamic Coefficients

P. Matta, M. Arghir, Université de Poitiers, Poitiers, France

Circular air bearings are perhaps the simplest devices for supporting a lightly loaded and high speed rotating shaft. Their advantages and drawbacks are rather well known and are well predicted by numerical codes. Nevertheless there is a lack of experimental data concerning especially the dynamic characteristics. The goal of this work is the development of a test rig that aimed for measuring their static and the dynamic characteristics. The test rig consists of a 50 krpm spindle entraining a 30 mm shaft. The shaft is supported by a hybrid journal bearing fed with water at pressures up to 100 bars. The test bearing is overhung in order to enable a rapid dismount from the rotor. The bearing casing is not completely floating on the rotor because it is mounted on a flexible squirrel cage. The static and the dynamic loads are applied by a spring and by a two electromagnetic shakers. The casing is provided with four proximity probes and two accelerometers. The dynamic forces are also measured on the casing. The bearing static working conditions are characterised by speed and load. For each set of working conditions the dynamic coefficients are measured by sweeping the allowable excitation frequency domain. Test results are presented and compared with theoretical predictions for a circular aerodynamic bearing of 30 mm diameter, L/D=1 and 22 µm clearance.
9:30 – 10 am
A Test Rig for Evaluating Gas Lubricated Bearing Performance

N. Ene, F. Dimofte, A. Afjeh, The University of Toledo, Toledo, OH

The objective of this paper is to describe a test rig for evaluating the static and dynamic performance of both thrust and journal air bearings. The rig can run at speeds up to 75,000 rpm. The shaft is supported by active magnetic bearings. They allow to precisely control the shaft position and to whirl the shaft at any frequency inside the bearing clearance. A special holding device supports the test bearing. The holding device permits to accurately position the bearing sleeve with respect to the shaft and to measure the steady-state and dynamic components of the bearing forces. A data acquisition system records the force and position signals from the load cells and magnetic bearing controller, respectively. Preliminary tests of an air lubricated journal bearing having a diameter of 30 mm, a length of 54 mm and a radial clearance of 30 microns revealed the possibilities of this test rig.

10 – 10:30 Break

10:30 – 11 am
Tests of Wave Bearings with PVD Coatings for Aerospace Transmissions

F. Dimofte, The University of Toledo at NASA GRC, Cleveland, OH, N. Ene, The University of Toledo, Toledo, OH, R. Handschuh, T. Krantz, U.S. Army Research Laboratory at NASA GRC, Cleveland, OH, F. Oswald, NASA Glenn Research Center, Cleveland, OH

A review of tests performed on wave bearings that have PVD (Physical Vapor Deposition) coatings on the active surfaces is presented. The tests have been performed on dedicated test rigs to impose typical operating conditions for aerospace wave bearings in order to evaluate the PVD coatings properties for aerospace-transmission applications. Various promising coatings were initially tested. Results of the tests for various types of PVD coatings are discussed and compared to the performance of uncoated bearings. Later on, the investigation was narrowed to Diamond Like Carbon (DLC) and Titanium Carbide (TiC) coatings. Preliminary analyses of the coatings before testing as well as post analyses were performed. 1000 Start-stop cycle, oil starvation and oil-off tests were performed but the oil-off test revealed the coating performance better than other tests. Discussions with coating manufacturers and characterization of the coating performance with nano indentation tester help improve the coating performance and achieve consistent test results such as running the bearing without oil supply more than 100 hours.

11 – 11:30 am
Application of Modified Direct Algorithm for Multi-Objective Optimization of Air Bearings

N. Wang, C. Chan, Chang Gung University, Tao-Yuan, Taiwan

In this study an efficient multi-objective optimization method is presented for optimizing an externally pressurized air bearing. A form of revolutionary algorithms is usually the method chosen for solving multi-objective optimization problems. The de facto standard criterion in the search for solutions of non-dominating objectives, satisfying the goal of multi-objective optimization, is Pareto optimality. However, the revolutionary algorithms are computationally intensive methods designed for robust global search, but not for efficiency. In this study, a global optimization method, DIRECT (Dividing RECTangles) algorithm, is modified as the global optimizer for the multi-objective optimization. The efficiency (execution time and required function calls) of this novel method is compared with an approach using GA in an air bearing optimization study. In the modified DIRECT algorithm the search is performed in various sized boxes (subspace) simultaneously. In the same box size group the boxes give non-dominated solutions that are subdivided for further search. As a result, the search is conducted in both global (based on the box size) and local (based on the Pareto optimality) searches. The computations are executed in a workstation which is capable of executing eight computing threads simultaneously. It is noted that both the DIRECT algorithm and GA are suitable for parallel computing. The preliminary results show that the modified DIRECT algorithm for multi-objective optimization is a very efficient method in the illustrated four-factor two-objective air bearing design.

11:30 – Noon
Multi-Objective Optimization of Air Bearing Using Genetic Algorithms

N. Murmu, Central Mechanical Engineering Research Institute, Durgapur, India

Multi-objective design optimization of porous air bearing is considered in the present study with supply pressure, porous pad diameter and thickness, permeability of porous material as design variables. The pressure generated in the
parallel surface bearing is obtained by solving interactively steady state is viscous compressible fluid Reynolds’ equation for air film and Darcy’s law for porous material. Since pressure distribution of the air film is a function of aforementioned four design variables, the goal of this study is to find an optimal solution setting for these variables with high confidence to satisfy multiple objectives simultaneously. The task is to maximize load capacity and bearing stiffness while limiting the air flow of the bearings. NSGA-II implementation written by KanGAL, IIT Kanpur is used as the optimization engine. These multi-objectives are performance measures of the air bearings, competing among themselves giving a trade off region where they become simultaneously optimal i.e. Pareto Optimal. The study presents a sensitivity analysis on various design parameters and discusses the effects of various for performance improvement.

**LUBRICATION FUNDAMENTALS III**

**Session Chair:** P. Aswath, University of Texas at Arlington, Arlington, TX  
**Session Vice Chair:** R. Mourhatch, University of Texas at Arlington, Arlington, TX

**8 – 8:30 am**  
**Carbon Nano-Onions as Lubricants. Experimental and Computer Modeling**  
J. Martin, University of Lyon - Ecole Centrale de Lyon, Ecully, France, N. Matsumoto, N. Ohmae, University of Kobe, Kobe, Japan, L. Joly-Pottuz, University of Lyon INSA - MATEIS, Villeurbanne, France, E. Bucholz, S. Sinnott, University of Florida, Gainesville, FL

Carbon nano-onions (COs) were synthesized by annealing nano diamond powder at high temperature. Typically, nanoparticles present a round-shaped nested structure containing or not a residual diamond core. Ultimately, they have a polygon-sahped structure. Tribological properties of COs were investigated both at nano (AFM) and macroscale as additives in a base oil. In the former case, friction coefficient lower than 0.01 was obtained for CO with diamond core. Friction coefficient obtained are also very low at about 0.06. Typically below 0.05 and good antiwear properties are demonstrated when COs are used as additives. Lubrication mechanisms of COs were investigated by HRTEM on wear debris and Raman spectroscopy in worn surfaces. Results show that COs can support high load but may be exfoliated into graphite and graphene sheets. Computer simulations verify the high loads that are supported by the COs and the only structural changes predicted to occur involve changes from three-fold to four-fold coordination within and between the COs as the compressive load is increased. At lower normal loads a combination of rolling and sliding is evidenced, sliding being affected by the formation of bonds between the COs and with the substrates.

**8:30 – 9 am**  
**Effect of Boron Containing Additives on Antiwear Performance and the Properties of Tribofilms Generated by ZDDP and Fluorinated ZDDP**  
R. Mourhatch, P. Aswath, University of Texas at Arlington, Arlington, TX

High frequency reciprocating rig (HFRR) and ball on cylinder type lubricity evaluators were used to probe the effect of the presence of Boron containing engine oil additives on the antiwear performance of ZDDP and Fluorinated ZDDP. Chemical composition of the tribofilm samples generated during these tribological tests was studied using X-ray absorption near edge structure (XANES) spectroscopy. Nano-scale mechanical properties of these tribofilms were also investigated using a nano-indenteter. Nano-indentations tests were performed to measure hardness values and moduli of the tribofilms while nano-scratch and nano-scale scanning wear tests were performed to evaluate the resistance of these films to mechanical shearing as well as their adherence to the steel substrate. Research was supported by Platinum Research Organization.

**9 – 9:30 am**  
**Contribution of Passenger Vehicles to Air Pollution in America and the Search of Environmentally Benign Engine Oil Additives**  
K. Komvopoulos, A. Tsai, University of California, Berkeley, CA

Societal concerns for climate changes, global warming, and air pollution have increased dramatically recently. These undesirable environmental changes are largely due to primary and secondary pollutants released by different industries. Global awareness has forced governments to institute stringent regulations to reduce or reverse these negative
environmental impacts. Since emission control systems or after-treatment devices (ADT) control tailpipe emissions, it is necessary to maintain the systems in their optimal condition to reduce harmful tailpipe emissions, including but not limiting COx and NOx. However, phosphorous in the most common antiwear additive zinc dialkyldithiophosphate (ZDDP) poisons the ADT. ZDDP degrades the efficacy of catalytic converters to reduce tailpipe emission via phosphorus poisoning. This problem can be solved by improving the retention rate of lubricants in engines and reducing phosphorus leakage into ADT. Another solution is to reduce the ZDDP content in the engine oil. However, reducing ZDDP may jeopardize the service life of the engine due to lack of good antiwear protection. Hence, the development of ZDDP-substitutes capable of reducing or eliminating ADT poisoning while maintaining or improving antiwear performance to increase the vehicle operation life is critical. The objective of this paper is to provide a general assessment of vehicle-induced pollution in America and demonstrate the antiwear efficacy of new blends with reduced ZDDP contents.

9:30 – 10 am
Comparison of the Experimental Results on Boundary Lubrication Film’s Molecular Orientation Measured by High Sensitivity Polarized Reflection Infrared Spectroscopy with Its Molecular Dynamics Simulation Results with Discover, MS

T. Suzuki, AIST, Tsukuba, Japan, W. Suetaka, Tohoku Univ., Sendai, Japan, T. Ikeshoji, AIST, Tsukuba, Japan

Molecular orientation of lubricant films, containing linear hydrocarbons as a main ingredient of several hundred Angstrom thickness, in the pressurized and heated interface between Fe or Au plate, and KBr or LiF prism, have been studied with a high sensitivity reflection polarized infrared spectroscopy. By evaluating the dichroic ratio of the symmetric and asymmetric stretching vibration mode of the methylene groups in the linear hydrocarbons, whose direction of the dipole moment shift is perpendicularly intersecting each other, it has been examined the linear hydrocarbon molecules have been aligned with its linear chain’s direction nearly perpendicular to the surface at room temperature. The orientation has become random upon rise in temperature. The roles of fatty acids as additives are to maintain the orientation of hydrocarbons until higher temperatures and to be increasing the effect by matching carbon chain length to that of hydrocarbon has been clarified. Even at the room temperature. Isotropic films of lubricant have been obtained by the addition of bulky acid. While according to the recent molecular dynamics simulation study, it has been reported that the linear hydrocarbons have been aligned normally to the surface under some specified sliding condition, and these reports might be contradicting against the result described above supported traditional mechanism of the boundary lubrication model. So we have re-examined the result by molecular dynamics simulation method with Material Studio 4.3 Discover module, to evaluate the experimental validity.

10 – 10:30 am  ★ Break

10:30 – 11 am
Design of Smart Nanocomposite Coatings for Extreme Tribological Conditions Under Boundary Lubrication

A. Erdemir, O. Eryilmaz, M. Urgen, Argonne National Laboratory, Argonne, IL, K. Kazmanli, Istanbul Technical University, Maslak, Turkey

Nano-composite and/or -layered coatings represent an new trend in surface engineering field and hold great promises for a wide range of demanding tribological applications. Specifically, their multi-functional nature makes them ideal for extreme tribological conditions where not only low-friction and -wear but also extreme resistance to scuffing and corrosion is needed. In this paper, we introduce the general principles of a crystal chemical model that can help indentify the kinds of coating ingredients that are needed in smart nano-composite coatings with a potential to provide ultra-low friction and extreme resistance to wear and scuffing under severe boundary lubricated sliding conditions. Using this model, we recently designed and synthesized a series of MoN-based nano-composite coatings and confirmed their superior tribological properties under both dry and lubricated sliding conditions. Employing advanced analytical tools (such as time-of-flight secondary ions mass spectrometry, x-ray photoelectron spectroscopy, and Raman spectroscopy) we ascertained the chemical nature of tribofilms forming on the sliding surfaces of these nano-composite films and correlated these findings with their superior friction, wear, and anti-scuffing properties. Overall, crystal chemical model used in this study seems to provide a new scientific means for the design and production of next generation nanocomposite coatings that can endure harsh tribological conditions in lubricated contacts.
Technical Sessions

11 – 11:30 am
Development and Characterization of Thermal Films on Ferrous Substrates from Antiwear Additives

B. Kim, P. Aswath, University of Texas at Arlington, Arlington, TX

Tribofilms formed at contacting surfaces protect the surfaces by creating a tribofilm. The tribofilms chemistry and properties are dependent on the additives used in the lubricant as well as the tribological conditions responsible for the formation of the tribofilm. This includes the temperature and shear stress. Many studies have shown that a thermal route to form films provide valuable insight into the mechanism of formation of tribofilms. In this study a thermal approach was used to study the kinetics of thermal films formed on ferrous substrates for a variety of antiwear chemistries that include Zinc Dialkyl Dithiophosphate (ZDDP), short and long chain ashless dialkyl dithiophosphates and amine phosphate. The thermal films were deposited on ferrous substrates by immersion in an oil containing these additives at a nominal concentration of 0.1 wt.% phosphorous for durations ranging from 1 to 60 minutes. The chemistry of the films were analyzed using X-ray absorption near edge spectroscopy (XANES). The nano-mechanical properties for the thermal films were characterized using nano indentation, nano scratch, and nano wear tests. This research was supported by Platinum Research Organization.

11:30 – Noon
Simulations of Lubricants Between Aluminum and Alumina Surfaces: From Quantum Chemistry to Continuum Models

L. Kong, C. Denniston, M. Muser, University of Western Ontario, London, ON, Canada, Y. Qi, General Motor Research, Detroit, MI

We present molecular dynamics simulations of generic lubricant molecules (olefines) sliding past aluminum and alumina surfaces. The goal of these simulations is to parameterize system and interface-specific phenomenological properties such as pressure and shear-rate dependent viscosity, compressibility and shear. Besides presenting results, we will report on the technical challenges that needed to be overcome in the mapping from the quantum-chemical to the atomistic scale and from the atomistic to the continuum description.

METAL WORKING I

Session Chair: S. Erhan, Polartech Additives, Inc., Bedford Park, IL
Session Vice Chair: R. Butler, Chemtool, Inc., Crystal Lake, IL

8 – 8:30 am
Friction in Metal Forming Processes – A Study Using Experiments and Simulation

P. Menezes, K. Kishore, S. Kailas, Indian Institute of Science, Bangalore, India, M. Lovell, University of Wisconsin-Milwaukee, Milwaukee, WI

Friction has an important influence in metal forming processes. By controlling the surface texture of the die, the interfacial friction can influence the net shape of the finished work-piece. The die surface can also affect the strain-rate distribution in the work-piece, which is believed to ultimately determine the microstructure evolution of the deforming material. Thus, the die surface finish could be manipulated to obtain desired microstructure within the finished work-piece. In this study, unidirectional and random surface finishes were produced on steel plates. Experiments were then conducted using Al-Mg alloy pins that slid against steel plates of different texture. In the sliding experiments, a high friction value was observed when the pins slid perpendicular to the sliding direction and a low friction value occurred when the pins slid on the random surfaces. FE simulations were then performed using the measured friction values to understand the stress and strain evolutions of various textures. Numerical results showed that the states of stress and strain rates are strongly influenced by friction at the interface, and hence would influence the final material microstructure. To substantiate the numerical results, laboratory compression tests were conducted. Surface textures on the die were attained so as to experience different friction values at different locations. A large variation in the microstructure at these locations was observed during experiments, verifying the hypothesis that surface texture and friction influence fundamental material behavior.
8:30 – 9 am  
**Friction and Transfer Layer Formation in FCC Metals: Role of Surface Texture and Roughness Parameters**  
P. Menezes, K. Kishore, S. Kailas, Indian Institute of Science, Bangalore, India, M. Lovell, University of Wisconsin-Milwaukee, Milwaukee, WI

It is believed that surface texture influences friction and transfer layer formation during sliding. In the present study, three well-defined surface textures – namely unidirectional, 8-ground, and random – were employed on steel plates. The unidirectional and 8-ground surfaces were respectively obtained by grinding the steel plate in a unidirectional manner and a criss-cross pattern. Random surfaces, on the other hand, were produced by polishing the plates using various abrasive powders. Experiments were conducted by sliding pins made of FCC metals (Al, Cu and Pb) against the steel plates using an inclined pin-on-plate sliding tester. Tests were conducted at a sliding velocity of 2 mm/s in ambient conditions under both dry and lubricated conditions. The morphologies of the worn surfaces were observed using a SEM. Surface roughness parameters of the plate were measured in the direction of the sliding on the bare surface away from the wear tracks using an optical profilometer. It was observed that the transfer layer formation and the value of the friction (including adhesion and plowing components) depend primarily on texture of plate surfaces. The effect of surface texture on the friction was attributed to the variation of the plowing component of friction for different surfaces. It was also observed that among the surface roughness parameters, the average or the mean slope of the profile, \( a \), correlated best with the friction. Furthermore, dimensionless quantifiable roughness parameters were formulated to describe the degree of plowing taking place at the asperity level.

9 – 9:30 am  
**Environmentally-Friendly Machining Temperature Analysis for Reaming with Minimum Quantity Lubrication**  
S. Kurgin, J. Dasch, D. Simon, General Motors, Pontiac, MI, G. Barber, X. Wang, Q. Zou, Oakland University, Rochester, MI

A series of cutting experiments was performed on an aluminum automotive transmission component with minimum quantity lubrication (MQL), or air-oil mist, an environmentally friendly alternative to traditional coolant. The purpose of the experiments was to determine the effect of coolant properties, cutting tool material and other machining parameters on the temperature of the work piece. In addition, traditional flood coolant tests were performed as a baseline for part quality and spindle power consumption. The results showed that cutting tool material and MQL delivery system type have the most significant impact on temperature and quality for reaming silicon-aluminum. Another finding is that with proper parameter selection, MQL performs equivalently or better than traditional flood coolant in terms of part quality and spindle power consumption.

9:30 – 10 am  
**The Influence of Amine Structure on Performance of Registered Biocides in Metalworking Fluids**  
P. Brutto, C. Coburn, D. Green, A. Jones, C. Nash, ANGUS Chemical Co., Buffalo Grove, IL, J. Pohlman, Dow Biocides, Buffalo Grove, IL, B. Pyzowski, R. Swedo, ANGUS Chemical Co., Buffalo Grove, IL

Amine size, structure and number of functional groups are expected to influence performance of registered biocides in metalworking fluids. This paper will attempt to quantify this relationship based on controlled laboratory experiments. Effects on cast iron corrosion control and pH stability during microbial challenge will also be reported.

10 – 10:30  
**Break**

10:30 – 11 am  
**Microbial Biofilms in Metalworking Fluid Systems**  
T. Williams, D. Reynolds, Rohm and Haas Co., Spring House, PA

Metalworking fluid (MWF) provides an excellent environment for the growth of microorganisms. Most of the studies on microbial populations and biocide efficacy testing in MWF have been focused on the organisms in the recirculating fluid (planktonic phase) due to easy access of samples and simple test methods. Microbial growth in dynamic systems also occurs to an equal or greater extent on the surfaces (biofilms) of the machines, tank walls, weirs, filters, and distribution lines. Evaluating microbe levels and testing biocide efficacy in microbial biofilms is challenging and not
straight forward as in testing liquid samples. New methods and approaches are required. Much has been learned about biofouling on surfaces over the past 20 years. This presentation will provide a review of the basic structure, function, composition, and test methods for microbial biofilms. Results of lab efficacy studies on the effect of biocides to control biofouling on surfaces will be presented.

11 – 11:30 am
Non-Tuberculous Mycobacterial Biofilm Development in Metalworking Fluids Using the CDC-Bioreactor

L. Rossmoore, C. Cuthbert, C. Cribbs, K. Rossmoore, Biosan Laboratories, Inc., Warren, MI

Non-Tuberculous Mycobacteria (NTM) have been implicated in outbreaks of hypersensitivity pneumonitis (HP) among industrial metal-grinding machinists. NTM are capable to grow in metal working fluids (MWF’s) to colonize surfaces and form biofilms. Bacteria within biofilms are more resistant to suboptimal growing conditions such as nutrient deprivation, extreme temperature changes, and antimicrobial treatments than the sessile counterparts. A greater understanding of NTM biofilm processes in MWF’s is important from the standpoint of developing new effective control strategies for fluid management including fluid choice and biocidal control. A standard bacterial and fungal inoculum of metalworking fluid field contaminants including Gram-negative Pseudomonads, NTM and fungi were introduced to the CDC-Biofilm Reactor (CBR) and different MWF formulations including straight, semi synthetic and synthetic fluids were tested for biofilm development. The CBR is a continuously stirred flow reactor with high wall shear. A poly-microbial biofilm was developed in the different fluid formulations using the continuous flow mode with interrupted batch modes to simulate field conditions. At certain intervals samples were taken for biofilm assessment by scraping the biofilm from the coupon surface, disaggregating the clumps then diluting and plating for viable cell enumeration and identification of primary and secondary colonizers. The results indicated the effect of different fluid formulations on biofilm development.

COMMERCIAL MARKETING FORUM III

Session Chair: Deborah Purnell-Otey, Rohm & Haas, Inc., Westville, NJ

8 – 8:30 am
Introducing LUBRIZOL® 5411: Advanced Slideway Lubricant Additive Technology

J. Purnhagen, The Lubrizol Corp., Wickliffe, OH

The Lubrizol Corp. introduces LUBRIZOL® 5411, a new additive package for the production of high performance slideway lubricants. This product delivers exceptional extreme pressure and demulsibility properties, allowing for the ability to meet the stringent performance requirements of General Motors’ LS-2 specification. At lower treat rates, the same additive package will meet all required performance of Cincinnati Machine specifications, including a very robust stick-slip result. In addition to performing to the defined industry specifications, LUBRIZOL® 5411 offers light color, ease of filterability and good compatibility with aqueous metalworking fluids in the machine tool.

8:30 – 9 am
Asteric Viscosity Modifiers – Breakthrough Polymer Technology for High Viscosity Index Lubricants

B. Schober, PhD, The Lubrizol Corp., Wickliffe, OH

Original equipment manufacturers and end users are demanding high efficiency lubricants that save energy, perform better and last longer. Lubricant marketers want to address these needs with differentiated products that are more profitable for them and offer their customers more value. High Viscosity Index (High VI) fluids represent one approach to increasing efficiency and performance for mobile hydraulic and power transmission applications. High VI fluids flow better at low temperatures so fluid friction is lower and the equipment is ready to work faster during cold start up. They also retain viscosity better at high temperatures to maintain hydraulic pump efficiency and protect components. Lubrizol’s new Asteric™ polymethacrylate viscosity modifier technology was developed to meet industry needs for better performing, more efficient lubricants. Asteric polymers have radial or star architecture which helps overcome tradeoffs seen with conventional viscosity modifiers – creating performance and formulating advantages. In comparison to conventional PMA products, Asteric viscosity modifiers work better, have more formulating flexibility and can more easily achieve very high viscosity index in the finished fluid. High viscosity index fluids formulated with Asteric viscosity modifiers have shown improvements in both efficiency and fuel economy in laboratory rig testing and in the field.
Technical Sessions

9 – 9:30 am
Benefits of Synesstic™ Alkylated Naphthalene (AN) Basestocks in High Performance Lubricants
S. Mazzo-Skalski, ExxonMobil Chemical Co., Houston, TX
ExxonMobil Chemical's Synesstic™ Alkylated Naphthalene (AN) Basestocks offers formulators a blend component which can improve the thermal and oxidative stability of lubricants blended with Group I, II, III, and IV basestocks. Used in a similar manner to esters, Synesstic™ AN Basestocks provides good additive and deposit solvency while providing seal swell capability. However, when replacing esters, Synesstic™ AN Basestocks may offer improved additive effectiveness and hydrolytic stability further enhancing the performance.

9:30 – 10 am
New Multi-Metal Corrosion Inhibitor for Water Soluble Metal Working Fluids
S. Seibel, Ciba Corp., Tarrytown, NY
IRGASOL® CI 5080 is a multi-metal corrosion inhibitor developed for water soluble Metal Working Fluid (MWF) applications. This product has been developed specifically for corrosion inhibition of ferrous and non-ferrous metals. Designed for use in milky soluble formulations, IRGASOL® CI 5080 is completely soluble in water and glycol which also makes it effective in synthetic and semi-synthetic formulations or as a top-treat additive via tank-side addition. The IRGASOL® CI 5080 works as a secondary emulsifier to help stabilize soluble oils. Performance in aluminum is resilient even at high alkaline conditions and IRGASOL® CI 5080 can be used in removal fluids and cleaners. IRGASOL® CI 5080 is stable under hard water conditions, and can be used alone or synergistically with other corrosion inhibitors. Totally organic in nature, IRGASOL® CI 5080 is free of amine, boron, phosphate, and silicates.

10 – 10:30 * Break

10:30 – 11 am
Advances in Digital Refractometry for Better Process Control
A. Nelson, ARN Engineering LTD, Perrysburg, OH

11 – 11:30 am
Multimetal Corrosion Inhibitor for Top-tier Lubricants
V. Bajpai, D. Chasen, Ciba Corp., Tarrytown, NY
Longer drain intervals, EGR & smaller engines based on non-ferrous metals are some of the trends known to result in increased acid build-up in engine oils leading to thermal degradation, deposits, sludge formation & corrosion of engine-bearing materials. Moreover, reduction of zinc levels in engine oil formulations is known to decrease yellow metal-bearing protection. Besides this, Fuel economy has come under increased focus especially during the recent years with increased use of friction modifiers & several of these chemistries can be aggressive towards engine-bearing materials. To better monitor corrosion problems, there are industry tests/procedures such as ASTM D 6594 (HTCBT), Sequence VIII & MACK T-12. On the Industrial side, reservoir/systems are getting smaller & being worked at increased pressure with longer fluid life expectations. This results in higher operating temperature which in turn leads to faster thermal degradation of the fluid, sludge formation & corrosion of the equipment. The search for alternate energy sources has increased the utilization of alternate systems such as solar and wind turbine technology. The latter system, due to the extreme conditions & environment in which it is used, is known to develop zinc corrosion. This presentation reviews traditional methods of protecting yellow metals & evaluates the utilization of synergistic combinations of additives to meet the more challenging requirements of both Engine & Industrial lubricant applications.

11:30 – Noon
Dow Ucon Synthetic Lubricants – Innovations
P. Pendergast, The Dow Chemical Co., Midland, MI
For over 25 years, Tannas Co. has anticipated the technical requirements for good lubrication, developed innovative laboratory instruments to meet those requirements, and understood both the customer’s and industry’s technical needs.

Some Examples:

Scanning Brookfield / Gelation Index Test... non-liquid, SBT Direct Cool
- Eliminates flammable bath medium
- Dual, independent test sample design
- Small bench-top footprint
- Datalink up to four units on one Laptop
- Enhanced SBT Automation Package
- Improved precision over liquid bath predecessors manufactured from Tannas

RPVOT Oxidation D2272 Test... non-liquid Quantum Oxidation Tester
- Eliminates hazardous hot oil baths
- Single position ‘stand-alone’ design
- Small bench-top footprint
- Quick turn-around time between tests
- Convenient features
- Automation Package available for multiple unit operation

Brookfield D2983 Viscosity Test... air in liquid SimAir® Test Cell
- Eliminates need for large, cumbersome air or programmable liquid baths
- Needs only small constant temperature liquid bath
- Improved precision and efficiency
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Environmental friendly fluids I

Session Chair: D. Smith, Omni Tech International, Ridgefield, CT
Session Vice Chair: B. Sharma, NCAUR/USDA/ARS, Peoria, IL

8 – 8:30 am
Soybean Lubricant Market Opportunities
D. Smith, OmniTech International, LTD, Midland, MI

Studies supported by the United Soybean Board over the past several years identified target market segments for introducing soybean oil into lubricants. Since that time significant advances have been made in technology for growing and modifying soybean oil and other natural materials. Use of renewable materials is now assigned a higher priority. Market prices for both petroleum base oils and naturally derived oils have also changed dramatically. Taken together, these changes modified how companies look at market opportunities for profitable soybean oil containing lubricants. A recent United Soybean Board study by Omni Tech International updates the perspective on appropriate product research by identifying market opportunities and application requirements which must be met by competitively successful soybean oil containing lubricants. Realistic commercial opportunities are identified within target market segments including total loss, transformer oil, metal working fluid, hydraulic fluid and engine oil. Key players, commercial lubricants in use, market size and growth, suppliers and consumers, technical and economic performance requirements, unmet market needs, specific product application opportunities, obstacles to market entry, regulatory requirements and environmental constraints/opportunities are identified. The importance of green, renewable technology and the regulatory environment to this target area is discussed.

8:30 – 9 am
Formulating and Testing of Engine Oils with Bio-Content
F. Lockwood, D. Dotson, The Valvoline Co., Lexington, KY, D. Smith, Omni Tech International, Midland, MI

Bio-derived materials with suitable molecular weight for use in engine oils are available in the market today in many forms; ranging from raw vegetable oils to materials that are essentially synthetic. They have potential use as base oils or additives in engine oils due to their positive qualities; excellent viscosity index, volatility, friction/wear reducing characteristic, and classification as renewable materials. These advantages are in most cases discounted by poor low temperature behavior and oxidative stability. Manipulation of the engine oil formula and use of a robust additive package is needed to allow any use of the lower cost vegetable oils, while new and expensive bio-synthetics are currently “niche” materials. In this work we assessed various laboratory engine oil screening test methods for the ability to predict performance in engines of oils that incorporate bio-derived materials vs. conventional materials. Oxidation performance was quickly identified as the main hurdle for successful screening in the lab bench tests and prediction of engine test results. Promising formulations were identified but may still not be competitive in cost. The ever increasing demands of automotive manufacturers for longer drain oils with greater oxidation life presents a barrier to the introduction of engine oils with bio-derived content.

9 – 9:30 am
Biobased Electrorheological (ER) Fluids from Suspensions of Modified Starch in Soy Oil
R. Narayan, D. Graiver, Z. Yang, Michigan State University, East Lansing, MI

ER fluids (also known as “smart” or “intelligent” fluids) are suspensions of fine, non-conducting particles in an electrically insulating oil. Such fluids undergo a dramatic and reversible change in their apparent viscosity in response to an external electric field and typically change within a few milliseconds from a consistency of a low viscosity liquid to a gel. The change in the apparent viscosity is reversible, and when the voltage is turned off, the viscosity decreases rapidly back to the original viscosity of the suspension. ER fluids are practical in various engineering devices and can be used as hydraulics valves, clutches, brakes, active and variable damping devices, shock absorbers, hydraulic actuators, engine mounts, etc. Most of the current ER fluids are based on synthetic oils and polymers. Here we will present our results on a biobased suspension derived from chemically modified starch particles in soy oil.
9:30 – 10 am
Heavy Duty Engine Oils with Vegetable Oil and PAO Blends
K. Hope, Chevron Phillips Chemical Co., Kingwood, TX, B. Garmier, Renewable Lubricants Inc., Hartville, OH
As discussed in the prior STLE papers, there are several performance challenges that are encountered when formulating engine oils with biodegradable vegetable oils. However, there are also benefits of lubricants that are considered to be biobased such as low volatility, excellent lubricity, exceptionally high viscosity indices utilizing oils from renewable resources. The challenges are in maintaining good oxidative stability and low temperature properties. This paper is a continuation to the 2008 paper (High Performance Engine Oils with Vegetable Oil and PAO Blends) that addressed how those performance challenges could be met by using Polyalphaolefins and the proper chemistry to improve the stability and viscosity properties while also meeting future emission and fuel economy requirements. Biobased engine oils will be reviewed with regard to typical engine oil performance properties used in fleet and/or commercial equipment. Engine oil analysis will be used to determine engine soot levels, fuel dilution, and wear. In addition, reduced emission and higher energy efficiencies are discussed based on the very high viscosity indices that are achievable with vegetable oil and PAO blends.

10 – 10:30 am ♦ Break

10:30 – 11 am
Polyalkylene Glycols and Their use in Hydraulic Fluids for Environmentally Sensitive Areas
M. Greaves, The Dow Chemical Co., Horgen, Switzerland, G. Khemchandani, The Dow Chemical Co., Freeport, TX
Natural and synthetic ester based hydraulic fluids are often the preferred choice for use in hydraulic equipment where the risk of spills and leaks to the environment is a concern. An alternative choice is the use of polyalkylene glycols (PAG) which offer excellent reliability for mobile and stationary equipment used in most climates and have favorable environmental profiles. Several benefits of PAGs are highlighted including their superior hydrolytic stability, non-sheening performance and their ability to minimize deposit build up in equipment. The use of PAGs as a co-base fluid in environmentally friendly formulations is also discussed particularly where it is important for fluids to have a high renewable content to meet environmental accreditations.

11 – 11:30 am
Biodegradable Lubricants – Real World Performance
M. Miller, Terresolve Technologies, Eastlake, OH
This paper scientifically, objectively and quantitatively compares vegetable based and synthetic biodegradable hydraulic fluids to petroleum fluids. Testing was done at independent laboratories, by the U.S. Military, by Original Equipment Manufacturers, and by long term field trials. This testing shows that the performance of biodegradable lubricants is equivalent to petroleum fluids. The benefits of biodegradable hydraulic fluids are well known. Their biodegradable properties allow them to break down in the environment reducing the negative impact from leaks and spills. They can be non-toxic, are renewable and reduce dependence on foreign petroleum oil. Conventional knowledge has focused on the limitations of vegetable oils as base stocks for lubricants. The weakness of the oxidative stability, the cold temperature performance and incompatibility with elastomers is well documented. Over the past decade improvements in vegetable base stocks, biodegradable synthetic base stocks, performance chemistry, and formulation expertise have allowed the development biodegradable products with performance equivalent to petroleum fluids. Several commercially available biobased, biodegradable synthetic and petroleum fluids were tested for physical and chemical characteristics, application performance, dielectric properties, seal compatibility, military and OEM Specifications, OEM evaluations and field performance. Each parameter was evaluated utilizing industry recognized testing protocol. The results of each test is reviewed and supported with the original data, and tables or graphs.

11:30 – Noon
Conversion to and Performance of Biodegradable Lubricants in Over-Water Applications
A dockside facility located on Puget Sound in WA which supports research, development, testing and evaluation of military and commercial projects, has recently converted to readily-biodegradable lubricants in several applications. This paper will review the conversion process from petroleum-based to vegetable-based lubricants and the subsequent performance of biodegradable lubricants in over-water applications.
Technical Sessions

Session 3J – NANO TRIBOLOGY III – NANOPARTICLE RESEARCH

Session Chair: M. Zou, University of Arkansas, Fayetteville, AR
Session Vice Chair: D. Demydov, University of Arkansas, Fayetteville, AR

8 – 8:30 am
Preparation and Tribological Properties of Lubricating Oil-based Nanofluids Containing Metal or Graphite Nanoparticles

C. Cheol, O. Jemyung, J. Mihee, KEPRI, Daejeon, South Korea

Oil-based nanofluids were prepared by dispersing several metal or graphite nanoparticles in lubricating oil. Agglomerated nanoparticles were dispersed evenly with a high-speed bead mill and/or ultrasonic homogenizer and the surface of nanoparticles were modified simultaneously with several dispersants. Their tribological behaviors were evaluated with a ball-on-disk and four-ball testing machine. It is obvious that the optimal combination of nanoparticles, surfactants and surface modification process is very important for the dispersity of nanofluids, and it eventually affects the tribological properties as a controlling factor. Results indicate that relatively larger size and higher concentration of nanoparticles lead to better load-carrying capacity and antiwear property. In contrast, the use of smaller size and lower concentration of particles is recommended for reducing the friction coefficient of lubricating oil. Moreover, nanofluids with mixed nanoparticles of Ag and graphite are more suitable for the improvement of load-carrying capacity and anti-wear property.

8:30 – 9 am
In-situ Studies for Lubrication Mechanisms of Nanoparticles

F. Dassenoy, M. Belin, L. Joly-Pottuz, J. Martin, ECL, Ecullly, France, B. Reynard, G. Montagnac, ENS, Lyon, France

One of the main challenges in lubrication is the search for suitable lubricating solutions in order to strongly reduce the environmental impact related to the massive use of polluting additives. The use of nanoparticles as additives of lubrication is more and more considered. Tribological performances of lubricants containing nanoparticles in dispersion (carbon nanotubes, IF-MS2 …) are spectacular [1-4]. Strong reductions of both friction coefficient and wear are observed. Post-mortem physico-chemical characterisation of surfaces are usually performed to get knowledge of the tribofilm composition. Nevertheless, in situ tribological tests are essential to progress in the understanding of the lubrication mechanism of the nanoparticles. In this paper, we will present through some examples of nanoparticles recently studied the potential of some of these in situ techniques such as in situ Raman tribology and dynamic video tests [1-5].

9 – 9:30 am
Advanced Lubrication for Loaded Components

A. Adhvaryu, Caterpillar Inc., Peoria, IL, A. Malshe, University of Arkansas, Fayetteville, AR, A. Erdemir, Argonne National Laboratory, Argonne, IL, W. Jiang, nanoMech LLC, Fayetteville, AR

Systematic investigation of designed nanomaterials that positively impact fiction and wear behavior in dynamically loaded components. The efforts are focused on tribological testing, viscosity effects, dispersion phenomena and boundary film characteristics. Low SAPS approach will be discussed in the light of particle architecture and their impact on tribological properties and emission regulations. The major challenges facing nanomaterial based advanced lubrication will be discussed.

9:30 – 10 am
Design and Study of Molybdenum Sulfide Nanoparticles Based on Multicomponent Chemistry Using Phosphorous and Boron Components

D. Demydov, A. Malshe, University of Arkansas, Fayetteville, AR, A. Adhvaryu, Caterpillar Inc, Peoria, IL

The hybrid chemo-mechanical milling process of molybdenum sulfide with second component based on phosphorous and boron elements was used as a synthetic approach to prepare multicomponent nanoparticle additives. Their addition to base oil could provide advanced lubrication by: (1) supplying nanosized lubricating agents which reduce friction and wear at the asperities contact zone, (2) enabling strong tendency to adsorb on the surfaces, (3) reacting with the surface, so that lubricating tribofilms are formed, which offer ability to sustain high loads and distribute the load locally as well as
respond and sustain under high temperatures, and (4) enabling all these at minimal cost and less environmental impact. The structural properties of novel additives were characterized using TEM, EDX, and particle size analysis. The tribological behaviors were compared using Four Ball and Block on Ring tests. The formed tribofilms were studied using XPS, Auger, TOF SIMS, and FIB techniques.

10 – 10:30 am  * Break

10:30 – 11 am
Fundamental Understanding Role of Metallic Nanoparticles on the Behavior of MoS2 Nanoparticles through the Study of Chemo-mechanical Properties of Tribofilm

W. Zhang, D. Demydov, A. Malshe, University of Arkansas, Fayetteville, AR, A. Adhvaryu, Caterpillar Inc., Peoria, IL, A. Erdemir, Argonne National Laboratory, Argonne, IL

Nanoparticles of MoS2 have shown excellent tribological properties. For obtaining greater film endurance, authors have experimented chemical synthesis route for synthesis of Ag nanoparticles (NPs) and then, integrating them with MoS2 nanoparticles using mechanical milling process. Authors have investigated chemo-mechanical properties of this multi-component inorganic chemistry through tribofilms. Three different Ag compositions were studied, ranged from 2-25 wt.%. XRD, EDS, TEM, and particle size analyzer techniques were used to examine structural properties, silver content, particle size and particle size distribution. Friction and wear properties were observed by pin-on-disc and then, tribofilm was characterized by TEM, SEM and EDS. DSC and TGA techniques showed that silver molybdate were formed at high temperature.

11 – 11:30 am
New Inorganic Fullerenes Nanoparticles (MoxW1-xS2): Influence of the Stoichiometry on the Tribological Properties

F. Dassenoy, J. Tannous, M. Belin, J. Martin, A. Bruhacs, W. Tremel, LTDS, Ecully, France

Tribological properties of IF-WS2 and IF-MoS2 nanoparticles have been extensively investigated in recent years [1-3]. These two metal disulfides are found to exhibit low friction and wear reducing in the lubricant. Researches conducted on these particles showed tribological properties superior to their classics forms. The fullerenes with their closed structure have a great chemical stability. Their round shape is also a favorable factor because it allows a seamless deformation. In this paper we describe a series of sliding experiments using a new kind of fullerenes nanoparticles containing both molybdenum and tungsten (MoxW1-xS2). Interesting friction reducing and wear properties were observed when these particles were added to the base oil. It was shown that the change in the molecule stoichiometry affects on the tribological performances of these nanoparticles. Transmission electron microscopy (TEM), X-ray diffraction (XRD), X-ray spectroscopy and in-situ video tribology were used to characterize the different systems and propose a lubrication mechanism.

11:30 – Noon
Surface and Interface Analysis of the Tribofilm Formed Using Passive and Active MoS2 Nanolubricant Additives

A. Verma, A. Malshe, C. Thompson, University of Arkansas, Fayetteville, AR, W. Jiang, NanoMech, Fayetteville, AR, A. Adhvaryu, Caterpillar, Peoria, IL

Understanding the mechanism for the deformation of nanoparticles under severe loading condition is vital for designing advanced lubricants. In this research, yielding of the nanoparticles forming tribofilm from passive (bare) MoS2 and active (functionalized with organic molecules, triglycerides and phospholipids) MoS2 nanoparticles were studied. Focus is on the surface and interface analysis of the tribofilm comparing the influence of organic molecules and inorganic nanoparticles in forming durable tribofilms and describing the underlying mechanism. Characterization was done using atomic force microscopy (AFM) for morphology, scanning/transmission electron microscopy (SEM/TEM) for nanostructures, energy dispersive spectroscopy (EDS) for chemical analysis, and nanoindentation for mechanical behavior. A tribofilm embedded with nanoparticles in an amorphous matrix was observed on the surface. Within ten minutes of testing under boundary lubrication condition, a continuous film of MoS2 started to form on the surface, islands approximately 3 microns in diameter and 120 nm thick (size of nanoparticle).
Tuesday, May 19

Technical Sessions

**SPECIAL SESSION ON COATINGS II**

**Session 3K  Yucatan 2**

**Session Vice Chair:** S. Ingle, Texas A&M University at Galveston, Galveston, TX

8 – 8:30 am  
**Genesis of Superlow Friction with Nano-smooth Diamond Coatings**  
M. De Barros Bouchet, C. Matta, Ecole Centrale de Lyon, Ecully, France, T. Gries, L. Vandenbulcke, CNRS, UPR3021, Orleans, France, J. Martin, Ecole Centrale de Lyon, Ecully, France

In this paper we investigated the friction behaviour of nano-smooth diamond coatings under high vacuum and with various added gases to elucidate the influence of different test environments. Glycerol, water, hydrogen and deuterium were introduced into the vacuum chamber at room temperature and 80°C. Specifically, the friction of nano-smooth fine-grained diamond coatings deposited on titanium alloy substrates by a MWPECVD method was studied. These nano-smooth diamond coatings display a smooth surface roughness in the 15-35 nm range coupled with high hardness and Young’s modulus. Their structure is revealed by transmission electron microscopy studies. While the friction coefficient is high under ultra high vacuum with diamond/diamond couples, ultralow friction with no wear is obtained in presence of OH-containing gases. Superlow friction (friction below 0.01) was also observed in presence of H2 and D2. The gas phase lubrication allows a better identification of the friction mechanism from advanced surface characterizations.

8:30 – 9 am  
**Tribochemical Effects on Friction and Wear Behavior of ta-C Coatings in Presence of Alcohols and a-C:H Coatings in Dry Conditions**  
C. Matta, Argonne National Laboratory, Argonne, IL, M. De Barros Bouchet, B. Vacher, Ecole Centrale de Lyon, Ecully, France, O. Eryilmaz, Argonne National Laboratory, Argonne, IL, T. Le Mogne, J. Martin, Ecole Central de Lyon, Ecully, France, A. Erdemir, Argonne National Laboratory, Argonne, IL

In this paper, we concentrate on two tribological systems that produce extremely low friction with no apparent wear. The first is a unique system composed of a pair of thin tetrahedral hydrogen-free amorphous carbon coating (ta-C) lubricated by pure glycerol at 80°C and the second is composed of a thin hydrogenated carbon coating (a-C:H) tested under dry sliding conditions. In order to understand the mechanism of low friction of both systems, we studied their surface chemical states by Energy-filtering transmission electron microscopy (EFTEM) coupled to focus ion beam and the combination of SIMS spectroscopy before and after tribotesting. For the ta-C coatings the presence of a very thin graphitic layer at the extreme surface was detected before sliding tests. EFTEM show a transformation of ta-C bulk structure from sp3 carbon to sp2 carbon, and the increase of the graphitic carbon at the top surface. This layer certainly helps the lubrication by glycerol. Then to understand the mechanism of low friction ToF-SIMS analysis were performed inside and outside the tribofilm. The result revealed the hydroxylation of the extreme surface of the coatings. For a-C:H coatings, EFTEM revealed an increase in sp2 carbon at the top surface after sliding tests which suggest tribo-induced phase transformation that influences wear properties of such films. Based on the results from both films, a mechanistic explanation will be provided for the superlow friction properties of DLC films under dry and lubricated sliding conditions.

9 – 9:30 am  
**Wear Mechanisms of DLC Coatings**  
K. Wang, Texas A&M University, College Station, TX, C. Lin, Baker Hughes, Inc., Houston, TX, G. Fox, H. Liang, Texas A&M University, College Station, TX

The diamond-like carbide has shown promising tribological properties as solid thin coatings. In the present research, we study the wear of two types of DLC coatings under severe wear conditions. The plasma-assisted chemical vapor deposition (PACVD) was used for depositing the coating on the 440C stainless steel substrate material. Different wear modes, abrasive, adhesion, and stick slip, were found. In this presentation, we discuss the relationships between the material capabilities (PV) and wear mechanisms and how laboratory observation correlates with field results.
9:30 – 10 am  
Tribological Behavior of Flame Sprayed HA Based Composite Coatings

V. Panavekar, Texas A&M University, Galveston, TX

Hydroxyapatite (HA) coatings by flame spraying technique resemble a weak structure. The mechanical and tribological properties of HA coatings can be enhanced by addition of hard ceramic particles. HA based composite coatings were obtained on SS 316L by flame spraying of composite powder with addition of titania, alumina and zirconia to hydroxyapatite. Tribological studies were carried out on as-sprayed and post treated flame sprayed coatings. It was observed that HA based composite coatings showed enhanced wear resistance as compared to as-sprayed HA coatings. Similarly erosion test were carried out by impacting alumina grits on the flame sprayed coatings. The volume loss of coatings was compared to the volume loss of coating obtained in wear test on coatings by Pin on Disc method and improved tribological properties of composite coatings was verified.

10 – 10:30 am  
Break

10:30 – 11 am  
Anti-Friction Coatings, Can this Established Technology Meet Future Challenges of Friction Reduction?

M. Jungk, V. Clerici, Dow Corning GmbH, Wiesbaden, Germany

Anti-Friction Coatings (also known as Dry Film Lubricants or Bonded Coatings) provide an elegant way to adhere the solid lubricant to the surface of the tribological contact by selected resin packages. In the last decades these high-performance lubricants have proven to be particularly effective for several machine elements when working under conditions of mixed friction; as a matter of fact Anti-Friction Coatings are able to provide a for-life dry lubrication in terms of coefficient of friction reduction and wear protection in several applications. Nevertheless there are limitations of their use in applications of high speed and the typical thickness of 10-20 micrometer is often considered too high. On the contrary Galvanic, Diamond Like Carbon (DLC) or Chemical Vapor Deposition (CVD) coatings sometimes lack durability due to their low film thickness. This presentation will try to compare strengths and weaknesses of those coatings and give an outlook on the “Ideal Tribo Coating” to foster further discussion.

11 – 11:30 am  
Fretting of WC/a-C:H and Cr2N Coatings Under Grease Lubricated and Unlubricated Conditions

B. Leonard, F. Sadeghi, Purdue University, West Lafayette, IN, R. Evans, G. Doll, P. Shiller, The Timken Co., Canton, OH

The fretting phenomenon was investigated experimentally in contacts between coated and uncoated steel rod and ball specimens generating a circular Hertzian contact. A fretting wear test rig equipped with a video camera was used to observe the effects of fretting on coated steel surfaces in both grease lubricated and unlubricated environments. Tungsten carbide reinforced amorphous hydrocarbon (WC/a-C:H) and chromium nitride (Cr2N) coatings were tested and compared. Fretting wear volumes and surface profiles are presented for both grease lubricated and unlubricated conditions. Videos of a coated ball fretting against a transparent sapphire flat were recorded and screen captures are presented. The role of normal load, lubrication, frequency, and amplitude of motion on the fretting wear of coatings is discussed. Lubricant released from the grease was observed to flow through channels in the stick zone of the fretting contacts. Both coatings were found to reduce fretting wear. WC/a-C:H was more effective at reducing wear under unlubricated conditions. WC/a-C:H decreased fretting wear more than Cr2N when delamination was avoided in grease lubricated contacts.

11:30 – Noon  
Friction and Wear Performance of WC/a-C:H Thin Films in Lubricated Rolling Contact

R. Evans, The Timken Co., Canton, OH

It is known that tungsten carbide reinforced diamond-like carbon (WC/a-C:H) thin films can be used on tribological surfaces in rolling element bearings and gears to improve friction and wear performance in general. However, recent work reveals that the magnitude of benefits achievable with WC/a-C:H coatings in lubricated rolling contacts depends highly on factors such as lubricant type and quantity, dimensionless lubricant film thickness (lambda), and slide-to-roll ratio (or % slip). Example tribotest and bearing fatigue test data are presented with an emphasis on the link between WC/a-C:H performance/durability and tribological contact conditions.
SYNTHETIC LUBRICANTS

Session Chair: L. Rudnick, Ultrachem, Inc, New Castle, DE
Session Vice Chair: J. Sherman, BASF, Wyandotte, MI

2 – 2:30 pm
Potential Biodegradable Lubricant Materials: Saturated Branched-Chain Fatty Acid Isomers

This presentation reports the zeolite-catalyzed synthesis of saturated branched-chain fatty acid (sbc-FAs) isomers (commonly referred to as isostearic acids). Sbc-FAs have the potential for being important materials for the production of biodegradable lubricants, emollients and hydraulic fluids. Although there have been previous studies on the isomerization of monounsaturated fatty acids using clay- and zeolite-catalysts, these reactions suffered from moderate conversions, moderate selectivity and high amounts of undesired byproducts (10-50%). We recently found that modified Ferrierite zeolites isomerized the unsaturated fatty acids to sbc-FAs at high conversions and selectivity (with only 5-10 wt.% undesired byproducts). Sbc-FAs were characterized by GCXGC-TOF-MS. The physical properties of sbc-FAs as determined by low temperature studies, viscosity-index measurement, oxidative-stability determination, high frequency reciprocating rig test and four ball wear test showed that sbc-FAs are good lubricant candidates for several applications. In particular, the lubricity tests indicate that the synthesized materials are superior to mineral oil (a common petroleum-based material) in several tests. To evaluate the potential of this process for large scale production, we also developed a process model to estimate production costs for preparing sbc-FAs. Based on the analysis model, the process was found to be cost-effective indicating that it can potentially be developed for the large-scale production of useful sbc-FAs.

2:30 – 3 pm
Corrosion Properties of Ionic Liquids at Elevated Temperatures and Humid Conditions
N. Doerr, C. Gabler, A. Schneider, AC2T research GmbH, Wiener Neustadt, Austria

Studies of ionic liquids have shown promising tribological properties, in particular high load carrying capacity. Higher thermal stability and very low tendency towards volatility have initiated intense research in the field of ionic liquids as lubricants. But until now, low attention has been paid to corrosion properties especially of partly degraded ionic liquids as it can be expected during application. For this reason, selected ionic liquids based on the bis trifluorosulfonylimide anion have been stressed by artificial ageing. The effect of temperature variation, the presence of water and the addition of corrosion inhibitors on metal surfaces was studied. Dissolved metals were determined by ICP-OES and surfaces affected were analysed by SEM. The findings clearly showed a strong dependence on the cation chosen. Water played also an important role in the initiation of corrosion. Further, it can be demonstrated that corrosion prevention can be successfully introduced by a proper choice of the corrosion inhibitor. Summing up it can be stated that the formulation of lubricants based on ionic liquids has to be carefully adapted to the chemical structure of the ionic liquid and corrosion inhibitor, the material to be lubricated and the environmental conditions.

3 – 3:30 pm ✯ Break

3:30 – 4 pm
The Tribological Properties of Phosphonium Derived Ionic Liquids
I. Minami, Iwate University, Morioka, Japan

Ionic liquids are one of the new class synthetic lubricants that possess non-volatility, non-flammability and excellent thermo-oxidative stability. Another feature of them is “designable fluids.” Various ionic liquids can be developed by adequate combination of anionic and cationic moieties. In our previous work, we have evaluated the effects of anionic moiety on tribological properties of 1,3-dialkyylimidazolium salts. In brief, hydrophobic anions provide better tribological properties than hydrophilic anions do. In this work, we focused on the effects of cationic moiety on the tribological properties. Tetra alkyl phosphonium salts were employed to ball-on-flat type tribo-test under boundary conditions. Higher alkyl group in the phosphonium moiety was found to be beneficial for friction reduction. Surface analysis of the rubbed surface with phosphonium salts suggested the formation of phosphate as boundary film. This is why phosphonium salts provide lower wear than imidazolium salts do. The anti-wear properties of phosphonium salts were much improved by the combination of halogen-free anions. The mechanism will be discussed in terms of corrosive wear.
4 – 4:30 pm
Aspects of Selecting the Optimum Fire Resistant Water Glycol Hydraulic Fluid
M. Greaves, Dow Chemical Co., Horgen, Switzerland, J. Knoell, Dow Chemical Co., Freeport, TX
Since their adoption over 50 years ago, fire resistant water glycol hydraulic fluids have played an important role in lubricating hydraulic equipment and providing improved fire safety compared to hydrocarbon lubricants. Over the years, incremental improvements in their performance have evolved in addition to improved fluid maintenance practices. Trends to higher industry operating efficiencies and increased hydraulic equipment operating pressures and temperatures will require more robust fluids in the future. Through the recent introduction of new water glycol hydraulic fluid technology, it is now possible to improve equipment reliability and fire safety and also reduce costs associated with fluid maintenance. The results of several successful field trials of a new fluid operating in harsh environments demonstrate higher stability and enhanced fluid longevity compared to traditional products. Aspects of the benefits of choosing premium fluids based on high quality raw materials versus cheap “bargain fluids” is also discussed.

4:30 – 5 pm
Air Compressor Oils – Critical Tests Defining Product Performance
G. Dudley, ExxonMobil Corp., Paulsboro, NJ
Air compressor lubricants must be designed to address and/or meet a number of severe service environments encountered during the operation of an Industrial air compressor. Key product performance expectations of a compressor oil include such characteristics as the ability to withstand high compression temperatures, atmospheric contaminants such as water contamination, resistant to auto-ignition, and provide extended drain intervals. The characteristics of a high performance compressor fluid should exhibit good water separability to minimize carry over effects, good oxidative stability as an indicator extended drain intervals, rust preventative characteristics to provide protection of internal compressor components from water contamination, and high auto-ignition temperature to reduced potential for fires and explosions. The ability of fluids to provide these characteristics is dependant on the basestock type and additive selection. This presentation will discuss 4 key performance characteristics associated with compressor lubricants and how they relate to proper lubricant selection and optimized compressor performance.

5 – 5:30 pm ★ Business Meeting
need to be studied to provide a fundamental understanding of the phenomenon. The simulation of contact mechanics with and without liquid mediated contacts based on a rough multilayered media can be an effective way to investigate these issues. A numerical three-dimensional (3D) rough multilayered contact model is developed based on a variational principle in which the contact pressure distributions are those that minimize the total complementary potential energy. The influence coefficients of the displacements and stresses for a multilayered contact model are first determined in frequency domain using Fast Fourier Transform (FFT) and then converted to real time domain using IFFT. Friction and wear trends studies based on the contact analysis of multilayered structures under both dry and wet conditions are performed. Optimum design parameters including materials with desired mechanical properties, layer thicknesses and surface roughness are identified.

3 – 3:30  ★ Break

3:30 – 4 pm
Wind Turbine Gearboxes: Ensuring Reliability with Optimized Oil Conditioning
D. Kolstad, Porous Media, St Paul, MN

With increasing energy costs and acute awareness and desire to develop clean, renewable energy, wind power is experiencing a remarkable period of growth. The gearbox is one of the most critical components within the wind turbine. After evaluating the fluid condition in a number of gearboxes, it has been confirmed that these critical components are subjected to excessive contamination, several times what is recommended by the manufacturer. This suggests that the likelihood of costly failure, outside of warranty, is quite high. Data will be presented to show how a unique dehydration and filtration technology has enabled these same turbines to be continually operated with the fluid in optimal condition. Applications using this technology have seen particulate contamination reduced by > 90% and moisture contamination reduced by 80-95%. Fluid condition improvements of this magnitude will minimize the potential for gearbox failure as well as lower the overall operation and maintenance costs.

4 – 4:30 pm
Wear Test for Motor, Hydraulic and Gear Oils
A. Kiehn, Bardahl Mfg Corp, Seattle, WA

This research looks at using standard wear and EP tests combined with oxidation testing as a means of evaluating the wear performance of typical lubricants including automotive motor oils, hydraulic oils and gear oils.

4:30 – 5 pm
Material Properties Important to the Metal to Metal Sliding Contact
T. El-Wardany, X. Luo, H. Zhang, J. Milton-Benoit, United Technologies Research Center, East Hartford, CT

Steels may exhibit significantly different tribological behavior although their ordinary mechanical properties are within specified ranges. The difference is usually related to the microstructure and associated unspecified properties which depend on the percentage of alloying additives and methods of production. For example, a small change of the additive percentage can facilitate generation of solid lubricant layer during the sliding contact and thus reduce friction. Therefore, it is necessary to identify less well-known properties that play key roles in the sliding contact of steels and correlate the friction to these properties and material chemistry. The current work focuses on determining the material property-dependence of each major component of friction involved in the sliding contact of cast iron-steel pair. For this purpose, the friction-wear properties of three low carbon steels with different chemical contents were evaluated by sliding them against cast iron blocks. It was found that the material constitutive law plays a significant role in defining the dynamic hardness and consequently the plastic deformation friction component. In addition, depth of penetration and height of plowed materials were highly dependent on the material flow stress. The sliding surfaces was further analyzed by using scanning electron microscopy (SEM) with energy dispersive X-ray microanalysis (EDX) and their topography was measured by using a white light interferometer. The observation revealed that the wear mechanism of steel specimens would depend on finer microstructure.
High Temperature Fretting Wear Mechanisms of a Ti Alloy: A Tribochemical Approach
C. Mary, T. Le Mogne, J. Martin, S. Fouvry, Laboratory of Tribology and Dynamics of Systems (LTDs), Ecully, France

One of the major issues for motorists is to predict how the components are damaged in service and to establish when they need to be replaced or repaired to avoid a catastrophic failure. Fretting wear is a surface degradation process induced by small-amplitude oscillatory movements between contacting bodies. It may result in critical wear, especially in the blade/disk contact of aero-engines. To focus on this industrial issue, an experimental layout was designed to perform fretting wear tests up to 500°C. Several geometries close to industrial contacts were studied and surface coatings were tested. Wear regimes were identified regarding to variations of parameters such as pressure, sliding amplitude and temperature. Chemical analyses (EDS, XRD, XPS) performed on fretting scars enabled the characterization of degradation mechanisms. Tribologically Transformed Layer appearing at the surface of the samples was characterized using TEM samples prepared by FIB nano-machining. These observations pointed out the effect of pressure on fretting wear mechanisms.

CONDITION MONITORING II

Session Chair: C. Chichester, Dow Corning Corp., Midland, MI

Recent Advances in Miniature Infrared Spectroscopy
R. Butler, Chemtool, Inc., Crystal Lake, IL

The slow down in the telecommunications industry has been a boon to instrumental spectroscopy. Some $20 billion originally invested in research of photonics technology for optical communications is now being re-employed as advances in infrared and Raman spectroscopy. Miniature scanning spectrophotometers covering both the near IR (NIR) region and the mid infrared region (MIR) have been developed. These small rugged spectrophotometers allow placement near the analyte in harsh field and industrial environments. While fiber optic cables have allowed NIR and Raman spectroscopy to bring remote sample information away from harsh environments to the lab instrument, this is not possible in the information rich MIR region. Fiber optic cables do not transmit in the MIR region so that the optical bench must be brought to the samples’ harsh environment. Different dispersive technologies such as miniature electro mechanical systems (MEMS) typified by Texas Instruments DLP chip used in televisions and micro-opto-electro-mechanical (MOEMS) are explained. New practical applications of multiplexing techniques such as Hadamard transform instruments are illustrated. Finally laser, LED and T-SLED (tunable super luminescent LED) sources are discussed. A discussion of suggested potential practical applications will follow.

Methods for Trending In-Service Grease Consistency with Small Sample Quantities
R. Wurzbach, York Laboratories, LLC, York, PA, R. L. Williams, MRG Power Labs, York, PA

Historically, standard grease analysis methods have been developed primarily to characterize manufactured greases for quality control and design characteristics. However, increased interest exists in analyzing in-service greases for condition assessment. The small quantities that are typically available from the operational and wear areas of operating machinery present a challenge in utilizing existing and traditional methods of analysis. One of the most important characteristics that is desired to be maintained in in-service greases is consistency. The use of a cone penetrometer often requires larger amounts of sample than the entire quantity involved in the lubrication of a given component, and therefore is not a useful test for this application. In recent years, greater use of a cone and plate rheometer is being seen as a way of evaluating in-service grease consistency, as this test can be performed with very small quantities. Additionally, other methods are being introduced to quickly and cost-effectively evaluate grease consistency of samples as small as 1 gram, through orifice extrusion under controlled conditions. This paper will compare such orifice extrusion methods to rheometer measurements for prepared samples simulating mixed and stressed greases, and evaluate the ability of these techniques to trend consistency changes with small sample sizes.

3 – 3:30 pm  *  Break
Technical Sessions

3:30 – 4 pm
Asset Health Management Best Practices
T. O’Hanlon, Reliabilityweb.com & Uptime Magazine, Fort Myers, FL
Asset Health Management involves strategies, techniques and technologies designed to provide accurate and real time information on the condition of rotating equipment, electrical gear and stationary equipment. Throughout 2008 the Association for Maintenance Professionals in cooperation with Reliabilityweb.com conducted a series of benchmarking exercises on the topic of asset health management by investigating practices around reliability, condition monitoring and the analytic information technologies being utilized by today’s best practice companies. Join certified maintenance and reliability professional Terrence O’Hanlon for a lively discussion to illuminate the elements required for a best in class asset health management program.

4 – 4:30 pm
Experiences in Lubrication of Ammonia Compressors
I. Mayr, AMI Agrolinz Melamine International, Linz, Austria, F. Novotny-Farkas, OMV Refining & Marketing, Schwechat, Austria, A. Schneider, Austrian Center of Competence for Tribology, Wiener Neustadt, Austria
The production of ammonia is a high pressure process which requires a compression of synthesis gas up to 300 bars. Turbo-compressors operating at those high pressures can place increased demand on turbine oil performance. The permanent presence of aggressive gas constituents means a challenge for the whole lubrication system and for the plant maintenance. This paper describes a case study about the experiences, gained over 30 year history of operation, lubrication and plant maintenance of ammonia compressors.

4:30 – 5 pm
Hard Particle Contaminants Affect Performance of Lubricants and Bearings
M. Moon, Bel-Ray Co., Inc., Farmingdale, NJ
Laboratory studies were carried out to investigate the effects of lubricant cleanliness on mechanical devices under controlled conditions. Lubricants were contaminated with hard particles and compared with relatively clean control oils. One test apparatus was a Graphite Lubricant Tester with a 1/40 hp AC electric motor. The motor rotated a shaft and impeller that circulated the lubricant and drove an unsealed ball bearing immersed in the oil. Contaminant particles caused wear and weight loss of bearings and, possibly, reduced the operating efficiency of the motor. Even relatively low concentrations of microscopic particles caused abrasive wear. True power (watts) was monitored as a time series. Distributions of data for clean lubricants were normal. Contamination and wear altered the skew and kurtosis (symmetry and peak shape) of the distribution of power data. Even relatively low levels of microscopic particles in lubricant under mild operating conditions (temperature, pressure, speed) can negatively affect mechanical devices and, possibly, energy consumption.

5 – 5:30 pm
IR Thermography a Useful Tool for the Condition Monitoring of Power Plant Mechanical and Electrical Components
K. Malik, Ontario Power Generation, Pickering, ON, Canada
IR Thermography is an integral part of Ontario Power Generation Nuclear Predictive Maintenance (PDM) and the Equipment Reliability Programs.

5:30 – 6 pm
Online Wear Monitoring of Spur Gears
H. Hirani, Indian Institute of Technology Bombay, Mumbai, India
Surface pitting of gear teeth has been of increasing concern for automobile industries. The pitting of gear teeth reduces the gear-mesh stiffness and therefore increases the vibration of gear box. In the present study, an experimental gear rig has been designed and developed to monitor the in-situ wear failure of spur gears by analyzing the measured acceleration signals. A magnetorheological fluid based dynamometer has been designed and developed to exert a torque load ranging between 1 N.m to 20 N.m. To verify the magnitude of the frictional torque, a rotary magneto-elastic torque sensor has been employed. A 10-HP motor with associated frequency drive has been used to regulate the rotational speed of motor shaft between 500 rpm and 24000 rpm. An accelerometer, displacement sensor (to identify
the start of a new cycle and completion of previous cycle), and rotation counter (counting the gear life in cycle) have been used. Time averaging and 1-D wavelet have been used to process the acquired data from accelerometer and displacement sensor. Finally, to validate the test setup a gear-pair having 23 teeth on pinion and 24 teeth on gear has been tested. The results of progressive tooth failure have been plotted in the polar coordinate to indicate the progressive failure of gear teeth. Trend analysis technique has been used to predict the gear pitting/cracking. Physical examination of the end of test indicated that the gears had worn by combination of surface wear and pitting. The photographs of pitted gear and (fresh and used) lubricant have been provided in the present paper.

6 – 6:30 pm  
**Acoustic Emission Activities During Incipient Damage Monitoring Under Different Loadings in Rolling Contact Fatigue Process**

Z. Rahman, H. Ohba, Toyo Electric Mfg. Co., Ltd, Yokohama, Japan, T. Yoshioka, T. Yamamoto, Tokyo University of Agriculture and Technology, Tokyo, Japan

The study focuses on the influences of contact conditions on the Acoustic Emission (AE) activities for incipient damage detection by loading on radially loaded two rollers from 3.0 to 4.0 GPa to simulate the conventional gear-pinion point or elliptic contact combination under rolling contact fatigue (RCF) tests. The AE hit counts pulse observations from detected AE signals were processed using AE signal enhancement techniques through the AE source locator to estimate the test-induced surface damage at its incipient stage of birth. The results based on experiments detailed the successful use of the combination of the AE monitoring and the AE source locator as a new technique for precisely detecting and positioning of the incipient damage irrespective of loading. The AE activities were influenced by load in terms of amplitude and energy parameters, and provided an indication of the defect size for monitoring the rate of further degradation of the rolling elements.

**ENGINE & DRIVETRAIN IV – FUEL IMPACT**  
**Session 4D ✽ Coronado D**

Session Chair: V. Wong, Massachusetts Institute of Technology, Cambridge, MA

2 – 2:30 pm  
**A Study of Biodiesel Fuel Impact on Lubricants**

D. Chasan, V. Bajpai, P. Fasano, E. Ng, Ciba, Tarrytown, NY

As fuel costs continue to rise and emission restrictions get tighter to control CO2 impact, there has been a rapid shift in the growth and use of alternate fuels such as ethanol blended gasoline and bio-diesel. This has, to an extent, been supported by legislation in various economies to reduce their dependence on crude oil imports needed for refining/sale of traditional fuels.

Biodiesel is one such type of renewable fuel that is made using Fatty Acid Methyl Ester (FAME) derivatives from sources such as soy, rapeseed/canola, corn, palm, jatropha, coconut, used cooking oil, animal fat, tallow, etc. Studies show that as a result of blow-by, biodiesel fuel tends to concentrate in engine lubricants more than traditional diesel fuel. The impact of biodiesel fuel on lubricant functionality can therefore be significant. This paper examines the impact of 6% biodiesel fuel dilution on a commercial SAE 15W40 CJ oil. Properties such as: oxidation stability, deposit formation, wear, corrosion and elastomer compatibility were analyzed and the findings are reported in this paper.

2:30 – 3 pm  
**Impact of Bioethanol-Containing Fuels on Engine Oil Performance**

K. Baumann, F. Novotny-Farkas, OMV Refining & Marketing, Schwechat, Austria

Bioethanol-containing fuels have been introduced as partly replacements for gasoline in several countries of Europe, USA and in other regions of the world. Bioethanol is not a new or unknown fuel constituent. This has been used in Latin-America since several years. Nevertheless, the influence of bioethanol-containing fuels on engine oil performance has not been enough investigated or published yet. In this paper the results of the laboratory and the bench tests, as well as the fleet tests will be presented, which were carried out with different bioethanol-gasoline blends in passenger car engines in Austria.

3 – 3:30 pm ✽ Break
Technical Sessions

3:30 – 4 pm

**Hard Deposits in the Combustion Chamber of Biogas Fuelled Stationary Gas Engines**

**N. Doerr, C. Besser, C. Schneidhofer, AC2T research GmbH, Wiener Neustadt, Austria**

Biogenic gas fuels from sewage, landfill, fermentation and wood gasification plants, cause an acceleration of oil ageing due to sulfur, nitrogen, silicon and chlorine compounds. Further, hard deposits on machine parts of the gas engine can be formed to influence operation parameters or to cause wear or even severe damage. Several machine components comprising cylinder liner, cylinder head, piston and piston ring were examined for hard deposits and abrasive wear due to hard particles by means of comprehensive REM studies. Considerable insights into the appearance, distribution and composition of deposits found in the combustion chamber have been gained. The presence of silicon-containing compounds – in particular from landfill gas – as well as ash-forming lubricant additives contributes to the formation of such deposits. Further, it can be shown that engine dynamics result into steady removal and formation of deposits accompanied by compression of deposits.

4 – 4:30 pm

**Tribological Aspects of a Diesel Injector Operation with Charcoal-Oil slurries**

**V. Soloiu, G. Molina, Georgia Southern University, Statesboro, GA**

Charcoal has been produced from wood by pyrolysis and ground. 25% charcoal by mass with average size of 10 microns was emulsified with heavy fuel oil (HFO), and produced a slurry with kinematic viscosity of 30-40 cSt and non-Newtonian fluid properties. Slurry’s combustion was successful for about one hour and after that the engine exhibited loss of power, increased smoke and decreased engine efficiency. The injection pump didn’t present abnormal wear and the investigation focused on the engine’s injector. A displacement sensor with resolution of 0.5 micrometers has been introduced into the injector to record the needle lift and it was found that the injector’s valve became stuck at some cycles and two areas were prone to that: the needle stem and the needle conical seat. To avoid the slurry entering around the needle’s stem, oil channels were machined into the injector’s body and a pressurized feeding system was built with hydraulic oil ISOVG32 fed up to 7 MPa while decreasing the recurrence of sticking. The injector has been tested with HFO after 50 hours of operations on slurry and it has been found that engine overall efficiency slightly decreased with the worn injector due to combustion deterioration as a result of nozzle orifices accelerated wear. The nozzle has been cut and the sticking area inspected by microscope. The needle’s guide was found without sticking but the injector needle’s conical seat showed abnormal wear after 50 hours of slurry operation with wear rate at least 4 to 8 times higher than that of same type injector working with HFO.

4:30 – 5 pm

**Business Meeting**

**FLUID FILM BEARINGS IV – MODELING**

**Session Chair: M. Braun, University of Akron, Akron, OH**

2 – 2:30 pm

**Mesh Movement Method for Transient Simulation of Annular Cavities: Application to the Prediction of Fluid Forces in Squeeze Film Dampers**

**E. Ngondi, T. Grönsfelder, R. Nordmann, Technische Universität Darmstadt, Darmstadt, Germany**

Computational fluid dynamics (CFD) simulations are used in addition to experimental work in turbomachinery research. Increasing computational power and feasibility of reliable CFD-solver makes it possible to solve complex problems. Different approaches for calculation of dynamic fluid forces uses the assumption of a circular centered orbit (CCO) to model the problem using a stationary simulation. As CCO assumption doesn’t match the real movement of the rotor, transient simulations are necessary for more realistic models. This work describes some mathematical algorithms which map a cylindrical, annular cavity into a rectangular, dimensionless coordinate system. According to grid quality aspects under displaced rotor position and compatibility with geometric boundary conditions one method is chosen to be the most suitable for the desired purpose. The proposed mesh movement approach combined with more realistic boundary conditions concerning an open ended bearing was used to the prediction of fluid forces in a squeeze film damper (SFD) executing CCOs at 6 different orbit radii between 0.4 and 0.9 relative to the nominal radial clearance. The parameter of the numerical model e.g. damper configuration, supply pressure, orbit radius and whirling frequency, were used on a SFD test rig to generate experimental results. Both results, the experimental and the numerical, are compared and discussed.
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2:30 – 3 pm

**Incompressible and Analytical Study on Strong Coupling Thrust Gas Dearing with Double Herringbone**

_S. Yao, Harbin Engineering University, Harbin, China_

Hybrid gas bearings could increase its load-carrying capacity and stiffness considerably, especially the high-speed bearings. In 1971 Fleming presented a hybrid gas bearing [1] with double columns orifices and a herringbone grooves and with a disturb method calculated its performance. It is witnessed that this bearing had a weakened performances including load carry capacity and stiffness under a small compressible number. This phenomenon had been explained in 2006 [2] by analytical analysis combined aerostatics and aerodynamics based on Whipple-like theory and the reason is that the structure coupling between aerodynamics and aerostatics weakened the performances. The groove configuration could be changed to overcome this disadvantage. This paper presents a strong coupling thrust gas bearing with double herringbone. Based on Whipple theory under incompressible condition the bearing geometry has been normalized with assumption of logarithm pressure distribution and components of load carrying capacity has been analyzed to some extend. This bearing integrates spiral groove self-acting effect, surface restriction function, and external restriction function to sufficiently promote gas bearing performances. The reaction between aerodynamic pressure and aerostatic pressure is eliminated successfully because of the self-balance in its aerodynamic effect. So it could be operated in a large speed range including stationary state.

3 – 3:30 pm  Break

3:30 – 4 pm

**Typical Strong Coupling Gas Bearings and Their Comparison**

_S. Yao, Harbin Engineering University, Harbin, China_

A linearization method was developed to describe couplings between aerodynamics and aerostatics in a spiral groove thrust aerostatic bearing, including pressure coupling, structure coupling, and their reaction, based on Whipple theory. Three typical configurations of strong coupling thrust gas bearings (CTGB), including In-pump type (ICTGB), Out-pump type (OCTGB), and Herringbone type (HCTGB), were constructed with the normalized analytical models set up by the mentioned method. Comparative studies to conventional orifice restrictor aerostatic bearings (STGB) in a static state were conducted. The OCTGB design resulted in a load capacity increase of four times (+300%) that of STGB and a stiffness improvement by six times (+500%) that of STGB, furthermore the HCTGB design showed an enhancement of five times (+400%) in load capacity and seven times (+600%) in stiffness compared to STGB. Simulation shows that moving to steady state conditions the performance of OCT and HCT bearings will improve further. Strong coupling journal gas bearings can be constructed based on the same principles and method. In the future it is foreseen that strong coupling gas bearings will replace traditional bearings (liquid bearings and ball bearings) in extensive application.

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**LUBRICATION FUNDAMENTALS IV**

Session Chair: J. Guervremont, Afton Chemical Corp., Richmond, VA  
Session Vice Chair: M. Patel, University of Texas at Arlington, Arlington, TX

2 – 2:30 pm

**Design of Experiment Approach Towards Development of Better Greases**

_A. Suresh, P. Aswath, University of Texas at Arlington, Arlington, TX_

Grease is a solid to semi-fluid product of the dispersion of a thickening agent in a liquid lubricant. They usually contain additional compounds that can improve the different parameters of the grease, by boosting existing properties, suppressing undesirable properties and introducing new properties. Since these additives can interact with each other synergistically by assisting each other or antagonistically, the interaction of thickeners and additives must always be considered. Thus, the statistical model, Design of Experiments (DoE) is used that helps identifying critical factors, revealing interactions (whether antagonistic or synergistic) and finding ideal process conditions that accomplish the targeted responses. Proper use of DOE can provide design equations that can assist in the development of new products with little or no additional experimentation. In the current work, the interactions between the following factors, Zinc dialkylin
dithiophosphate (ZDDP), molybdenum disulfide, graphite, polytetra fluoro ethylene and carbon black, was studied. The wear behavior was evaluated using the four-ball wear tests by modifying the ASTM Standard D 2266 to study the behavior of the grease chemistries under various conditions of temperature, load and duration. ASTM D2596 was the standard used to evaluate the extreme pressure properties of the grease using the Four-ball wear tester.

2:30 – 3 pm
Non-Newtonian Effects on Film Formation in Grease Lubricated Radial Lip Seals
P. Baart, P. Lugt, SKF Engineering & Research Centre, Nieuwegein, Netherlands, B. Prakash, Luleå University of Technology, Luleå, Sweden

Models for calculating lubricant film thickness in radial lip seal applications assume Newtonian lubricant properties where only the oil viscosity is taken into account. Lubricating greases show non-Newtonian behaviour and additional normal stress components develop which may contribute to the load carrying capacity. This study investigates the shear rheology of greases and determines whether this “normal stress effect” in grease can significantly contribute to film formation in radial lip seals.

The rheological behaviour of the grease is studied up to shear rates of $5 \times 10^4$ s$^{-1}$ in a rotary plate-plate rheometer at very small gaps of 25-500 $\mu$m. A rheology model for the grease has been developed to model the normal stress at shear rates up to $10^7$ s$^{-1}$. Subsequently, this model is used to predict lift forces, generated by this normal stress effect, for radial lip seal applications. The model results show that a lift up to 50% of the seals lip force can be expected for low contact pressure bearing seals. This percentage depends very much on the operating conditions: lip geometry, speed and temperature. For radial shaft seals with much higher lip forces this percentage is less than 5% and can be neglected. From these results can be concluded that, under certain conditions, non-Newtonian effects can give a significant contribution to film formation in grease lubricated radial lip seals.

3 – 3:30 pm * Break

3:30 – 4 pm
Activation Energy of Tribochemical and Heterogeneous Catalytic Reactions
C. Kajdas, Warsaw University of Technology, Plock, Poland, A. Kulczycki, Institute for Fuels and Renewable Energy, Warsaw, Poland, K. Kurzydlowski, Warsaw University of Technology, Warsaw, Poland, G. Molina, Georgia Southern University, Statesboro, GA

The decrease of activation energy (Ea) for heterogeneous solid catalysts and tribocatalysis effects has been usually assumed as a lower apparent activation energy. However, there is no detailed theory to explain such mechanism. The authors have recently hypothesized that for standard and catalyzed heterogeneous reactions, including tribochemistry ones, the same real Ea would be needed to initiate reactions, but the energy introduced as mechanical work would be accumulated in the solid, and then emitted as impulses of triboelectrons and/or photons to reach Ea where the reaction takes place. The model includes the angle at which the stream of emitted energy equals 3-5 eV, and this work reviews literature data that is consistent with the required anisotropy on angular distribution of exoelectrons emitted from perturbed surfaces, in particular from metal-insulator-metal thin films. This data is used to design a specific device for evaluating angular distribution of triboelectrons in a high-vacuum tribometer.

4 – 4:30 pm
Influence of Viscosity Modifiers on Hydrodynamic Friction
J. Holtzinger, Imperial College, London, United Kingdom, R. Mufti, Castrol Ltd, Pangbourne, United Kingdom, H. Spikes, Imperial College, London, United Kingdom

Polymeric viscosity modifier (VM) additives have been used to increase the viscosity index of engine, transmission and other lubricants for many years. It is well known that solutions of VMs exhibit temporary shear thinning under high strain rate conditions as are present in engine journal bearings. In the past, this shear thinning was regarded as undesirable since it may reduce hydrodynamic film thickness. However it is now recognised that VM solution shear thinning plays a useful role in reducing hydrodynamic friction. This paper explores the relationship between viscosity modifier shear thinning and friction. A variety of viscometers including an ultrahigh shear rate viscometer (UHSV) are employed to quantify the dependence viscosity on strain rate for a range of polymer solutions. Hydrodynamic friction is measured over the same strain rate range using a soft-EHL contact. The results help clarify the role of polymer shear thinning in reducing hydrodynamic friction.
Technical Sessions

4:30 – 5 pm
**Friction Coefficient Comparison of the DLC Films in Ocean Water, Air and Vacuum**
R. Statuti, L. Santos, P. Radi, V. Trava-Airoldi, INPE, Sao Jose dos Campos, Brazil

In industrial design, friction and wear volume directly affect productivity and machine life time. As competition increases within the global economy, more research has been dedicated to understanding the physics and chemistry of moving parts and to finding improved lubricants. Diamond-like carbon (DLC) films have been intensively studied as solid lubricants for nearly 30 years. Plasma-deposited hard hydrogenated amorphous carbon films have been used extensively, mainly as a mechanical protective coating, due to their high degree of hardness, low friction coefficient, and high resistance to mechanical wear. This paper reports on the results of tribological studies that compared the friction coefficient and wear volume of 316L stainless steel samples with DLC films, in contact with ocean water, air and vacuum. The DLC films were grown by using a Pulsed DC Plasma Enhanced Chemical Deposition (PE-CVD) technique. The friction coefficients and wear volume were studied as a function of applied load with constant sliding speed, using ball-on-flat devices in the reciprocating mode by using CETR UMT-2 tribometer. The sphere wear was measured by using Optical Profiling System Wyko NT1100, in agreement with the ASTM G40-99 norm. Also, the film’s atomic arrangements and graphitization level before and after tribotests were analyzed by Raman scattering spectroscopy. UV-Vis Spectrophotometry analysis of the ocean water before and after tribotests was also carried out.

5 – 5:30 pm
**Solution of Tribological Problems on a Compact Distribution Steam Valve for Capacity Type Expansion Machines of Rankine Cycle for an Automobile**
Matsumoto, Kenji; Honda R & D Co., Ltd, Automobile R & D Center, Saito, Bunichi; Honda R & D Co., Ltd, Fundamental Technology Research Center, Taniguchi, Hiroyoshi; Honda R & D Co., Ltd, Automobile R & D Center

A compact-sized in-vehicle Rankine Cycle that recovers exhaust heat with high efficiency and fuel economy has been developed. The system integrates a capacity-type compact expansion machine that uses high-pressure, and high-temperature steam, and a generator. The key component that determines the performance of the expansion machine is the distribution steam valve. The requirements for the valve to satisfy the performance are low leakage and low friction. However, it has been difficult to satisfy the requirements with the existing mechanisms and materials due to problems such as corrosion and lubricity. A valve has been designed that satisfies the requirements by letting H2O be retained on the surface of sintered carbon to improve wear resistance, and at the same time, by letting the valve surface dither during steam distribution to maintain the water. This is the report of the configuration and performance of the distribution steam valve for Rankine Cycle expansion machine.

5:30 – 6 pm  ◆ Business Meeting

METALWORKING II

Session Chair: R. Evans, Quaker Chemical, Conshohocken, PA
Session Vice-Chair: R. Butler, Chemtool, Inc., Crystal Lake, IL

2 pm – 2:30 pm
**Evaluating the Performance of New MWF Additives by Laboratory Based Test Methods and Correlating them to Field Performance**
S. Erhan, A. Nilpawar, S. Morton, R. Stubbs, Polartech Additives Inc., Bedford Park, IL

It is important to be able to evaluate additives under actual use conditions. This is especially true for lubricity performance because it is very difficult to make laboratory size testing equipment for every one of the numerous machining applications. In this presentation we will discuss the evaluation of new lubricity additives by correlating the results that were obtained from laboratory testing equipment such as the Hille Press, Twist Compression and the Microtap to a CNC machine and machine shop trials. We will also talk about the value of the versatility of these instruments whose testing parameters can be adjusted to the desired machining application.
2:30 – 3 pm  
**Real-time Testing of Bioburdens in Metalworking Fluids Using Adenosine Triphosphate as a Biomass Indicator**  

Adenosine triphosphate (ATP) assays have been used to quantify bioburden in clear fluids since the early 1950’s. The original methodology was labor intensive and required considerable laboratory skill. Over the past half-century, the protocol has been simplified substantially, but until recently, chemical interferences made it impractical to use the ATP test in metalworking fluids (MWF). This paper presents precision and bias statistics for a new test protocol for ATP in emulsifiable oil, semi-synthetic and synthetic MWF at end-use dilutions. Additionally, it presents the results of field tests in which ATP data are compared with other MWF condition monitoring data. The field evaluation demonstrates the applicability of the new protocol to MWF bioburden condition monitoring.

3 – 3:30 pm  
**Break**

3:30 – 4 pm  
**Emulsifiers with Improved Lubricity and Foam Suppressing Properties for Water Miscible Cooling Lubricants**  
M. Stolz, L. Boesing, Sasol Olefins & Surfactants, Marl, Germany

Fatty alcohol ethoxylates are manufactured by the ethoxylation of linear or branched C10 to C22 fatty alcohols. The products with 2 to 6 moles EO find widespread use as emulsifier in water miscible lubricants. Key properties where the products still can be optimised to deliver higher performance properties for the use in water miscible lubricants are: efficiency, low foam behaviour, oil solubility, lubricity and compatibility for liquid formulations. A set of new fatty alcohol alkoxylate emulsifiers were synthesised. Their application properties were compared to existing market products. The results of the experiments exhibit some remarkable improvements in the performance properties of the new emulsifiers over current market products. Their high lubricity and their low foaming tendency favour the products for metal working applications. The products are readily biodegradable and possess only a low aquatic toxicity. Sasol has introduced the C16/18 alcohol alkoxylates as MARLOX RT grades to the market.

4 – 4:30 pm  
**Tramp Oil and Cream in Metalworking Fluids**  
D. Hunsicker, Caterpillar, Inc., East Peoria, IL

This paper discusses the effects of clear oil contamination and water-in-oil emulsion (inert or cream) contamination of metalworking fluids (MWFs), emphasizing destabilizing effects of cream on emulsions and the biological contamination enhancement of cream in all MWFs (discussing how and why this occurs). It first defines the terms we are using then goes into the specific mechanisms that damage the MWF. It discusses the additives used in many of the oils that can contaminate MWFs and their effect on the MWFs and it discusses the products that can form when poor quality water reacts with components of the MWF. Finally, there are examples (from our shops) describing different types of contamination and the resultant effects, finishing off with our conclusions and a summary.

4:30 – 5 pm  
**Adenosine Triphosphate in Metalworking Fluids After Microbicide Treatment**  

The use of adenosine triphosphate (ATP) testing as a metalworking fluid (MWF) condition monitoring tool has been described in a separate presentation. This presentation demonstrates the use of ATP to track the effect of a microbicide treatment against both planktonic and biofilm microbial communities. Bench top microcosms are used to compare ATP and culturability data as a function of time, post-treatment. In a separate experiment, bulk-fluid ATP and culture test results are compared. Additionally, bulk fluid and biofilm ATP data are compared. The results demonstrate that efficacy against biofilm communities cannot always be predicted based on bulk-fluid data. Direct measurement of biofilm biomass enables fluid managers to apply more effective antimicrobial treatments to recirculating MWF in plant systems.

5 – 5:30 pm  
**Business Meeting**
COMMERCIAL MARKETING FORUM IV  
Session 4H  
**Session Chair:** K. Delaney, Cromwell, CT

**2 – 3 pm**  
**Afton Chemical’s 5th Annual Key Driver Seminar: “Fluid Power for a Better Future”**  
J. Etheridge, Afton Chemical Corp., Richmond, VA  
Fluid Power is a vital contributor to the success of our diverse global economy. Afton Chemical’s 5th Annual Key Driver Seminar will feature new developments in fluid power and how they may lead to a better future. Gain insight and knowledge on how the lubricants industry can help contribute to improvements in fluid power efficiency, compactness, and effectiveness. These improvements can lead to reductions in fuel consumption and energy use while improving the quality of life for all of us.

**3 – 3:30 pm  
Break**

**3:30 – 4 pm**  
**PCMC – The Classic Preservative for Metalworking Fluids and Lubricants**  
P. Wachtler, Lanxess Corporation  
PCMC’s effectiveness against bacteria, mycobacteria and fungi will be discussed. The EPA, FDA and NSF approvals for use as an antimicrobial in H1 lubricants (lubricants that may have incidental contact with food) will also be discussed. The presentation reviews properties of effective biocides for metalworking fluid and lubricant applications, and how p-Chloro-m-cresol (PCMC) fits against this profile. PCMC’s mode of action is discussed, and how its specific properties provide a beneficial profile for the effective preservation of metalworking fluids. The presentation also reviews the regulatory situation of PCMC, which is globally well positioned with all relevant approvals (REACH, BPD, etc), including approvals for incidental food contact lubricant applications. Additionally, the favorable environmental profile of PCMC, based on its good biodegradability and low persistence, will be discussed. Last but not least, the currently available LANXESS product range of PREVENTOL CMK (PCMC) based preservatives, enabling formulation flexibility with regard to the treatment of concentrates as well as post-treatment purposes, will be presented.

**4 – 4:30 pm**  
**Lubricant Raw Materials from Kyowa Hakko**  
B. Hanrahan, Kyowa Hakko USA, S. Elgin, IL  
Kyowa Hakko Kirin Group is a large Japanese producer of pharmaceuticals, nutritional ingredients, flavorings and synthetic chemical products. Kyowa Hakko Kirin Group started production in 1949 and is a world leader in fermentation of natural products including amino and nucleic acids. Our position in both renewable natural products and synthetic chemistry gives use the ability to take a wide range of natural molecules and then tailor them for a specific application through chemical synthesis. This ability has allowed us to develop a range of experimental high performance anti-wear and anti-friction additives that are metal free, phosphorous free with low in sulfur content. Kyowa Hakko Chemical manufactures a range of branched acids, branched alcohols and diols that find use in the lubricant industry.

**4:30 – 5 pm**  
**New Microtap Tapping Torque Test Software**  
H. Rowley, Microtap USA Inc., Rochester Hills, MI
ENVIRONMENTALLY FRIENDLY FLUIDS II

Session Chair: S. Erhan, USDA/ARS/NCAUR, Peoria, IL
Session Vice Chair: B. Sharma, USDA/ARS/NCAUR, Peoria, IL

2 – 2:30 pm
Lubricant Properties of Modified Vegetable Oils
B. Sharma, J. Perez, Pennsylvania State University, USDA/NCAUR/ARS, Peoria, IL, S. Erhan, USDA/NCAUR/ARS, Peoria, IL

Lubricants made from vegetable oils represent a small section of market today, but recent legislations in both the United States and Europe could begin to brighten their prospects due to their eco-friendly and biodegradable character unlike petroleum oil based products. In order to understand the effect of chemical modification, various epoxidized fatty acid methyl esters were prepared. Oxidation, low temperature, and frictional behaviors of these chemically modified oils were studied. The frictional behaviors have been examined as additives in hexadecane in a boundary lubrication test regime (steel contacts) using Langmuir adsorption model. The oxidation behavior was studied using pressure differential scanning calorimetry (PDSC), while the low temperature property was studied using pour-point measurements. Epoxidation of olefinic materials makes them more oxidatively stable, epoxidation of oleochemicals increases their adsorption to metal surfaces, epoxidation has a deleterious effect on a lubricants pour point and viscosity index. This information can be used to design suitable lubricant molecules that will have optimum structure for effective metal adsorption as well as exhibit excellent boundary lubrication properties.

2:30 – 3 pm
Biobased Lubricants
H. Benecke, S. Shaffer, D. Garbark, Battelle Memorial Institute, Columbus, OH

Chemical modification of vegetable oils such as soybean oil by addition of one or two ester groups across fatty acid double bonds results in significantly improved oxidative resistance while also generally improving oil lubricities. A range of viscosities have been obtained that should fit use of these lubricants in applications such as gear oils, cutting oils, hydraulic fluids and engine oils. The chemistries for lubricant preparation and some performance data will be presented.

3 – 3:30 pm *
Break

3:30 – 4 pm
Chemical Modification of a Sunflower Base Oil for Use as a Thermally-Stable Industrial Lubricant
M. Siniawski, L. Doezema, T. Hanashiro, G. Canzi, Loyola Marymount University, Los Angeless, CA

Vegetable oil based lubricant stocks are potential substitutes for petroleum-based stocks because they are environmentally friendly, renewable, less toxic and readily biodegradable. However, they are often limited in their application, as they typically perform poorly at increased temperatures due to oxidation. Many recent studies have addressed this issue through chemical modifications of potential vegetable oil base stocks. This purpose of this study was to further investigate the tribological benefits of modifying sunflower oil with free fatty acid additives. This study explored eight different fatty acids, including some that have not yet been examined. Changes to the fatty acid composition of the sunflower oil were confirmed via gas chromatography (GC). Sliding wear tests were conducted at a variety of temperatures with the various sunflower oil formulations. Some of the modified sunflower oils showed great potential in decreasing the surface wear and sliding friction at elevated temperatures up to 150°C.

4 – 4:30 pm
Thermally Stable Bio-Based Lubricants

Vegetable oils have a number of inherent properties that are advantageous over petroleum-base oils as the feedstock for lubricants; they are biodegradable, non-toxic and will not harm aquatic organisms or surrounding vegetation. They have inherently high viscosity index, high flash point, good lubricity (low wear) and they do not contain low volatile
fractions that could boil off at elevated temperatures, and they are relatively inexpensive when compared with current petroleum-based feedstock, which makes them attractive commercially. Although these are very desirable properties, to date, only a small fraction of lubricants are derived from vegetable oils. The main problem is the relatively low thermal and oxidative stability at elevated temperatures whereby the double bonds are degraded to form a crosslinked network. We will introduce and discuss a lubricant derived from soybean oil that is more resistance to thermo-oxidative degradation and compare it with other chemical modifications in the literature.

4:30 – 5 pm
Biological Waxes as Surface Coatings
R. Cooper, H. Lee, S. Butler, J. González, B. Vinson, H. Liang, Texas A&M University, College Station, TX
Waxy secretions produced by the roach aids it in maintaining a clean surface, even after running in dirt. The wax is collected from the roaches and tested with a tribometer to determine the lubrication ability of the wax. Furthermore, half-cell experiments of Mg are conducted to test the corrosion prevention abilities of the wax. The wax is characterized by using a gas chromatograph and mass spectroscopy to determine its composition. The wax was found to have similar lubrication properties as conventional automobile oil. A silicon substrate is coated with a layer of roach wax and is scanned by an atomic force microscope (AFM) to test the ability of the wax to repel dust on non-organic surfaces. The dust repulsion abilities and the lubrication properties can be applied to MEMS devices to increase efficiency and prevent dust contamination. In this presentation, we discuss our findings.

5 – 5:30 pm
Novel Macromolecular Antioxidant Technology for Biolubricants to Address Oxidative Stability Issue
A. Cholli, Polnox Corp., Lowell, MA
Polnox is developing novel antioxidant technology that addresses the inherent problem associated with biolubricants. The key fundamental issue for biolubricants is the oxidative stability. Oxidative stability of fuels and lubricants derived from bio-resources is inferior compared to fossil fuels and presents a key issue to the industry. Existing commercial antioxidants are not effective to stabilize plant and animal-derived biolubricants. There is a real need to develop a new antioxidant technology to make biolubricants as viable alternate products in a wide range of applications, and to assist in displacing petroleum-based lubricants. This will reduce our reliance on imported oil. Industry standard tests are used to evaluate these novel antioxidants in the most commonly used oils for biolubricants.

5:30 – 6 pm  EFF Technical Committee Business Meeting
dual-target magnetron sputtering. Titanium diboride deposited by this method had a hardness > 30 GPa. This paper will discuss the film structure and how such structure correlates with its tribological and mechanical properties.

2:30 – 3 pm
Tribological Investigation of Amorphous Carbon Films Using in situ TEM Nanomanipulation

A. M’ndange-Pfupfu, Northwestern University, Evanston, IL, O. Eryilmaz, A. Erdemir, Argonne National Laboratory, Argonne, IL, L. Marks, Northwestern University, Evanston, IL

The field of tribology has long suffered from the problem of buried interfaces, forcing researchers to conduct experiments blind to the underlying mechanical deformation and structural processes that dictate friction behavior. Using a unique in-situ TEM nanomanipulation technique, we can dynamically observe the sliding interface at the single asperity level. With the capability for chemical and structural analysis, we can carefully measure the friction and wear behavior of various samples with interesting lubricious behavior. Using electron diffraction, we have investigated the rotational disordering of graphitic nanocrystals under normal and shear stress. In addition, we have used chemical analysis (EELS) to examine the precise mechanisms of graphitization seen in ultra low friction diamond-like carbon films. Along with experimental and growth parameters such as the relative amount of hydrogen present, the bonding configuration at the surface has been shown to play a significant role in the film’s tribological properties, and we measure the changes during sliding in real time. With better understanding of fundamental nanotribological behavior, not only can we better engineer devices at the nanoscale, but we can extrapolate our knowledge to macroscale problems.

3 – 3:30 pm  ✠ Break

3:30 – 4 pm
Morphology and Wear Mechanisms of PA66/Carbon Nanotubes Injection Moulding Products

Y. Chen, The University of Hertfordshire, Hatfield, United Kingdom, L. Qiu, X. Liu, Taiyuan University of Technology, Taiyuan, China, Y. Xu, The University of Hertfordshire, Hatfield, United Kingdom

A study has been made of morphology, properties characterization and wear mechanisms of Polyamide66 (PA66) carbon nanotube composites. This paper presents the effect of the moulding conditions on the nanocomposites morphology and the relationship between morphology and wear mechanisms of the nanocomposites. The structure and morphology of the composites and the dispersion of the carbon nanotubes in PA66 matrix were analysed using Fourier transform infrared spectrometry, scanning electron microscopy and transmission electron microscopy. Both wear and friction tests of the injection moulded PA66/carbon nanotube composite products with different percentages of carbon nanotubes were performed using a twin-disc test rig running against steel. It is observed that the morphology of the specimens has a significant effect on the tribological properties and wear mechanisms of the PA66 nanocomposites. It is also evident that both the wear rate and friction coefficient of unfilled PA66 can be improved considerably by filling with carbon nanotubes.

4 – 4:30 pm
Measurement of Vertically Aligned Carbon Nanotube Array Bulk Friction in Contact with Silicon

C. Korach, SUNY-Stony Brook, Stony Brook, NY

Arrays of Vertically Aligned Carbon Nanotubes (VACNT) have been utilized in bulk form to measure the indentation response and friction coefficients in contact with polished silicon wafers. A section of 1mm long VACNTs, which has a contact area of 3mm2, was mounted with epoxy to an cylindrical aluminum stub of 4mm in diameter, and installed in a commercial nanoindenter which has long-range lateral translation capabilities. When load-displacement hysteresis measurements were performed on a silicon wafer, the VACNT array was found to stiffen with increasing load, have a larger unloading slope, and more residual deformation. Friction measurements were performed by contacting the silicon wafer and translating the silicon sample during a load-controlled scan. Lateral forces were measured by an aluminum beam transducer equipped with strain gages. Coefficients of friction were measured for normal loads between 15 and 100mN and found to range from 0.75 to 0.9. Post-scanning analysis of the VACNT contact surface by optical and scanning electron microscopy showed indications of tube flattening in a layer near the surface and fracturing of the VACNT bulk in the trailing region of the array. These results could be described as a stick-slip phenomenon for brush sections that have undergone fracturing.
4:30 – 5 pm
The Influence of Nano-Particles on the Functional Mechanisms of Additives in Automotive Lubricants
J. Choo, PETRONAS Research Sdn. Bhd., Kajang, Malaysia

Extended research in nano-particles over recent years has revealed that they impart improved tribological performances in friction and wear. Their potential as new lubricant technology has thereby received increased interest—particularly in automotive lubricants where increased fuel economy and durability, with restrictive chemical limits imposed on lubricants to reduce automotive emissions resulting in a reversal in performance, remain long-term industry drivers for advancement. Nano-particles are emerging to be materials that can provide a combination of all three attributes: low friction, improved anti-wear, cleaner chemistry. The Mini Traction Machine has been employed together with the Spacer Layer Imaging technique to study the synergistic-antagonistic interactions of carbon nanotubes, as model nano-particles, with a variety of single additive components in elastohydrodynamic lubrication. This work lays emphasis on how the influence of nano-particles, and their perceived lubrication mechanisms, is attuned to the functional mechanisms of component additives commonly employed in automotive crankcase lubricants.

5 – 5:30 pm  Business Meeting

SPECIAL SESSION ON COATINGS III Session 4K  Yucatan 2

Session Vice Chair: S. Ingole, Texas A&M University, Galveston, TX

2 – 2:30 pm
Comparison of the Friction Properties of DLC Coatings in DLC/DLC Contacts
B. Vengusamy, Imperial College London, London, United Kingdom, R. Mufti, Whitchurch Hill, Pangbourne, Reading RG8 7QR, United Kingdom, H. Spikes, Imperial College London, London, United Kingdom

Diamond-like-carbon (DLC) coatings are promising surface coating for automotive parts in terms of friction and wear performance and are beginning to be introduced in engines. It is hence interesting to understand their film-forming and friction reduction mechanism. It is important to appreciate that there are many different types of DLC coating and even that the same type produced by different manufacturers may not behave similarly. Lubricant manufacturers must be aware of these differences and be able to produce oils able to be effective with many types of DLC. In this study DLC-coated mintraction machine (MTM) ball and disc specimens were obtained from 6 manufacturers to span a wide range of DLC types (totally 12) including metal & non-metal doped, undoped, hydrogenated & hydrogen-free DLCs. The friction properties of these coatings were then measured in DLC/DLC sliding-rolling contact lubricated by additive-free mineral oil. Raman spectroscopy was employed to study the unrubbed and rubbed surfaces while optical profilometry and AFM were employed to visualize, quantify and understand the film forming and friction reduction mechanism. Tetrahedral amorphous carbons (ta-C) showed low boundary friction (0.05 – 0.06) and remaining all showed similar friction behaviour of the order of 0.08 – 0.12.

2:30 – 3 pm
Characterisation of the Tribofilm on a WC-DLC Coating Under Sliding-Rolling Contact Conditions

Diamond like carbon (DLC) coatings are currently one of the most interesting surfaces used for tribological applications as they can provide low friction, high wear resistance and are known to be chemically inert. Reports on low friction and low wear coefficients are largely restricted to dry/inert conditions and only recently have details been published on the interaction/performance of DLC in lubricated systems. This paper focuses on the additive/additive and additive/surface interactions in the steel/steel system and the WC-DLC/WC-DLC systems in a more realistic sliding/rolling contact, which is predominant at cam/follower and gear contacts. In this study, tribotests were performed on a Mini Traction Machine (MTM) using a 50% slide/roll ratio with oils containing corrosion inhibitor, friction modifier and anti-wear additive (five
blends) for twelve hours thus, tribofilm was generated on the contact surface. The topographical characterisation of the tribofilm was carried out using scanning electron microscopy (SEM) and atomic force microscopy (AFM) furthermoe, the chemical characterisation of the tribofilm was carried out using energy dispersive X-ray spectroscopy electron (EDX) and X-ray photoelectron spectroscopy (XPS). Raman spectroscopy was carried out on the tribofilm to investigate possibility of the formation of a graphitic nano-crystalline carbon layer under lubricated conditions. Thus, the current study gives insight into tribofilm characteristics for WC-DLC surfaces under lubricated rolling-sliding contact conditions.

3 – 3:30 pm  **Break**

**SOLID LUBRICANTS**  
**Session 4L  Yucatan 2**

**Session Chair:** A. Konicek, University of Pennsylvania, Philadelphia, PA  
**Session Vice Chair:** J. Keith, University of Florida, Gainesville, FL

3:30 – 4 pm  
**Cryogenic Friction Studies of Polymeric Solids**  
D. Burris, University of Delaware, Newark, DE, W. Sawyer, University of Florida, Gainesville, FL

There are a growing number of costly and nationally sensitive applications in space that are subject to dry sliding conditions at cryogenic temperatures. These conditions are difficult to design for and design engineers consistently report that cryogenic vacuum is the most challenging condition in which to operate. There is no fundamental understanding of variable (or cryogenic) temperature friction and there is a paucity of available data upon which to develop an expectation of performance. Both of these limitations are largely due to the difficulty in developing the instrumentation needed to conduct both practical and fundamental studies of cryogenic friction. This paper reports on recent efforts to make both practical and fundamental measurements of cryogenic dry-sliding friction and the steps taken to support the validity and accuracy of the measurements. Various measurement techniques were used and confirm field observations that friction coefficient may increase rapidly with decreasing temperature. Interestingly, similar behavior was found for non-polymeric materials as well.

4 – 4:30 pm  
**Expanding the Operational Range and Functionality of Temperature-Adaptive Solid Lubricant Coating Materials**  
C. Muratore, UTC/Air Force Research Laboratory, Wright-Patterson AFB, OH, J. Hu, UDRI/Air Force Research Laboratory, Wright-Patterson AFB, OH, B. Phillips, A. Voevodin, Air Force Research Laboratory, Wright-Patterson AFB, OH

Nanocomposite coatings exhibiting multiple temperature adaptation mechanisms have been shown to yield friction coefficients of less than 0.2 from 25-700 °C. Multilayered coatings consisting of adaptive nanocomposite lubricant layers separated by diffusion barriers to inhibit segregation and oxidation of the buried lubricant material allow adaptation to occur only upon exposure by wear, and increase the wear lives of adaptive coating materials both at static temperatures and over multiple thermal cycles. Further studies of the multilayered coating architecture described above were carried out to demonstrate a novel in situ wear measurement and failure warning system. With the wear detection system in place, luminescence spectroscopy was also performed in situ on high temperature sliding interfaces to allow identification of the onset and mechanisms of changes in surface chemistry at elevated temperature during sliding, without artifacts introduced by chemical reactions and crystal growth during cooling after testing and prior to analysis. Expansion of the temperature range to 1000 °C with the aid of this, and other in situ techniques to monitor surface structure at elevated temperatures and composition was explored.
4:30 – 5 pm
Investigation of Contact Pressure Limits of Molybdenum Disulfide Solid Lubricant Films
R. Colbert, J. Keith, University of Florida, Gainesville, FL, D. Burris, University of Delaware, Newark, DE, W. Sawyer, University of Florida, Gainesville, FL
The space environment, with high vacuum settings (1x10^-6 Torr) and a wide thermal range (T>200°C or T<0°C), is one of the most difficult tribological environments in which to operate. These environmental conditions have led to the use of thin solid films to prevent seizure of many joints where including highly loaded restraints and hinges. The solid lubricant thin films primarily used are molybdenum disulfide (MoS2) based, but the tribological performance of these MoS2 films under space relevant conditions remains largely unquantified. This study examines the pressure limits of self-mated MoS2 films in both ambient and high-vacuum environments. It also investigates the fundamental mechanical contact differences that occur with unidirectional versus bidirectional motion.

5 – 5:30 pm
The Effect of Methane and Acetylene in the Surrounding Test Environment on Tribological Behavior of Non to Highly Hydrogenated DLC Films
O. Eryilmaz, A. Erdemir, G. Kartal, Argonne National Laboratory, Argonne, IL
Diamond-like carbon (DLC) films have attracted an overwhelming interest in recent years mainly because of their unusual friction and wear properties. Tribological properties of DLC films may vary depending on the deposition conditions, as well as the surrounding environment. For example, hydrogenated DLC seems to work the best, while hydrogen-free DLC films work worst in inert or dry test environments. But our previous studies have shown that there is a dramatic reduction on friction coefficient and wear of hydrogen-free DLC films when the surrounding environment is hydrogen. It is clear that the presence of hydrogen in the deposition chamber or in the surrounding test environment makes a huge difference in the tribological behavior of DLC films. In this study, we explored the effect of addition of methane or acetylene in the surrounding test environment on tribological behavior of wide range of DLC films. Two sets of DLC films are grown by physical vapor deposition technique with plasma mixtures having H/C ratios of 0 to 10. All test were performed using pin-on-disk machines under 2-10 N loads and at 0.2 to 0.5 m/s sliding velocities. Near surface chemistry and depth profiles of sliding surfaces were analyzed by using time of flight secondary Ion Mass Spectroscopy (ToF-SIMS).

5:30 – 6 pm
Friction and Wear Maps as a Function of Humidity Gradient for DLCH35%
P. Radi, L. Santos, R. Statuti, L. Bonetti, V. Trava-Airoldi, INPE, Sao Jose dos Campos, Brazil
Hydrogenated diamond-like carbon films (DLCH35%) have attracted increased attention mainly for spatial applications due to its low friction and cold welding protection on space environment. The tribological behavior of these films is strongly dependent on the test conditions such as sliding speed, contact geometry, normal load and specially environment conditions. Humidity influences friction of DLC films because the interaction of the water molecules with the atoms on the DLC surface. This paper shows the influence of humidity on friction and wear of a high hydrogenated DLC films in order to establish the friction and wear dependence with water concentration. DLC films with 35% hydrogen content (DLCH35%) on titanium alloy (Ti6Al4V) substrate produced under strictly controlled growth conditions. The tests were carried out on reciprocating system on ball on plate configuration and for DLCH35%/DLC35% pair. Friction and wear maps are constructed for environment conditions varying from the vacuum to immersion on liquid water conditions. The results show that low variations on the humidity can influence on the friction and wear of the film.

6 – 6:30 pm  Business Meeting