PENNSTATE

Donald A. Streit
Director

Chao-Yang Wang
Associate Director

GATE
GRADUATE AUTOMOTIVE TECHNOLOGY EDUCATION
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Advanced Energy Storage Center

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FOCUS ON THE ELECTROCHEMICAL ENGINE LAB

1 kW Hydrogen Fuel Cell Research Engine

Director's Message

Featured in this newsletter is Penn State's Electrochemical Engine Lab, directed by Dr. Chao-Yang Wang. Regular features that will appear in this and future issues of the GATE Newsletter include the calendar of events, graduate fellowship news, FutureTruck 2000, and recent publications.

The goal of this newsletter is to disseminate information on the research and other activities underway at the GATE Advanced Energy Storage Center. I hope you will find this newsletter interesting and informative. If you have any comments or suggestions for future issues, please feel free to contact me.

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Electrochemical Engine Lab

In response to increased research and instructional needs for advanced battery and fuel cell systems and their application in ultra-clean, fuel-efficient vehicles, the Electrochemical Engine Laboratory was established at the Pennsylvania State University in 1997. Affiliated with both the Department of Mechanical Engineering and the Pennsylvania Transportation Institute, the lab is well equipped with an extensive array of experimental testing, field-testing, and computational modeling facilities, including hydrogen and direct methanol fuel cell test stands, a 1 kW hydrogen fuel cell research engine, a computation and visualization facility, thermal and chemical analysis equipment, two battery cyclers, a battery simulation test system, and a field testing facility.

The overall goal of the laboratory is to provide quality computational and experimental results that are directly applicable to existing and novel technologies and are of great value to program sponsors. Perhaps the greatest strength of the EC Engine Lab is its array of talented and ambitious personnel. Presently, the laboratory employs four Research Associates, and twelve graduate students, with more personnel being added in the near future. "Our experienced team has been developed to provide an interdisciplinary atmosphere of teamwork and cooperation, with experts in computational fluid dynamics, electrochemistry, thermodynamics, transport phenomena, combustion and chemical kinetics, experimental methods and theoretical analysis" says Dr. Chao-Yang Wang, Director. "These core skills provide the fundamentals for solving a wide variety of fascinating problems of great importance to society".

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FEATURED THIS ISSUE: Electrochemical Engine Lab

Electrochemical Engine Lab

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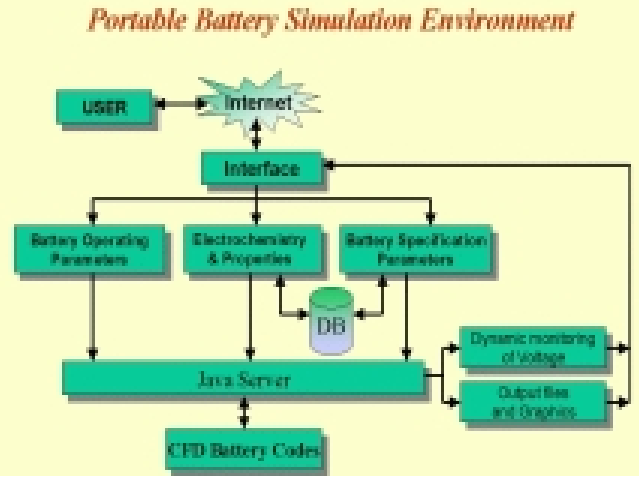
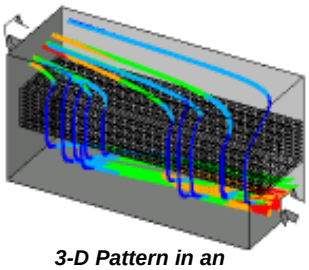
An example of the exciting applications developed at the EC Engine Lab is the creation of an internet-based battery simulation code for online simulation of several types of batteries with user-defined input parameters. The advanced code used accounts for such phenomena as coupled electrochemical and transport processes, electrodes surface passivation, and species transport by migration, diffusion, and advection. This on-line simulation is of enormous benefit to industry because it provides 24-hour access to immediate data on critical output such as state of charge, voltage, electrolyte composition, chemical reaction rate, and current density information, for a wide variety of advanced batteries. This greatly reduces the need for costly testing, and eliminates compatibility problems with the code because all software is run at the EC Engine Lab. Additional proprietary simulations can be utilized under a protected system. This novel online simulation can be found at: http://mtrl1/Simulation/Description.htm.



Battery CAD Systems (Internet-Based and Stand-Alone)

An ongoing project at the lab is the three-dimensional computer simulation of PEM hydrogen fuel cells. Motivated by the need for a hydrogen fuel cell device design and performance optimization tool, a multidimensional, transient model including electrochemical kinetics, two-phase flow, multi-component transport, current distribution, and heat transfer has been developed and validated with laboratory data. Major new output includes two-phase flow in the cathode and a 3-D comparison of conventional and interdigitated flow fields. Results indicated the superiority of interdigitated flow fields at high current densities. This novel code can also predict the effect of dilution of anode gas, a feature critical for study of the effects of various reforming processes for anode side gas flow.



3-D Pattern in an Interdigitated Cathode Flow Field

In addition, the simulation and field testing of hybrid-electric vehicle batteries is being conducted through a contract from the Defense Advanced Research Projects Agency (DARPA) through the Mid Atlantic Regional Consortium for Advanced Vehicles (MARCAV). The overall objective is to provide a new capability for battery designers and application engineers through combined simulation and field testing. One of the main goals of this program is to establish a cost-effective procedure for future battery design and application engineering. This will be accomplished by combining first-principle simulation with field testing to develop a portable simulation environment that will assist battery manufacturers and vehicle builders in computer-aided battery design, optimization and applications.

Penn State's Hybrid-Electric Vehicle

Field Testing Track Facility at PTI

Another important area under examination at the EC Engine Lab is the need for a more complete understanding and characterization of the nature of primary deterioration and failure processes in Valve-Regulated Lead Acid (VRLA), Nickel Metal Hydride (Ni-MH) and Lithium-Ion (Li-Ion) batteries, respectively. In a project sponsored by the US Department of Transportation Advanced Vehicle Program through Hawaii Electric Vehicle

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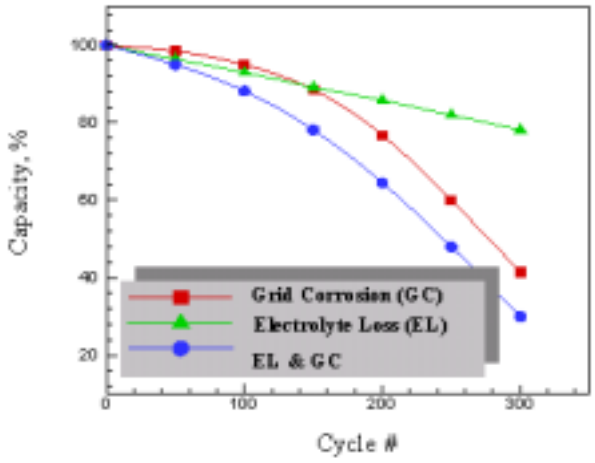
project will use the integrated experimentation and computational fluid dynamics (CFD) approach to develop a mathematical model describing these deterioration and failure processes as they affect the life and long-term performance of the batteries.



Predicted Capacity Loss of a Valve-regulated Lead-acid (VRLA) Battery Over Cycling

One of the exciting new projects the laboratory is researching involves the testing and simulation of direct methanol fuel cells (DMFC) for future application in automotive technology, sponsored by the Pennsylvania Department of Environmental Protection, the US Department of Transportation, and the Mid Atlantic Regional Consortium for Advanced Vehicles (MARCAV). Use of a direct methanol fuel cell, where liquid methanol is directly fed as fuel into the fuel cell, offers tremendous potential advantages over more mature fuel cell technologies involving hydrogen or reformed methanol, including lower parasitic system losses due to lack of reformer, greatly reduced system complexity and size, greater inherent reliability due to less equipment; and the ability to use fuel that is already commercially available and acceptable, with nationwide infrastructure already in place.

The overall objective of the project is to design, build and demonstrate DMFC stacks for auxiliary power or as a range extender for battery-powered heavy vehicles. A windowed 15 W direct methanol fuel cell test rig and control system has been designed and built, and is currently in initial stages of operation. Advanced computational fluid dynamics simulation of fuel cell operation will be used, in conjunction with experimental data, to define ideal operating regimes for DMFC use. Data acquired will include detailed analysis of the chemical species content and concentrations at various locations along both the anode and cathode flow path with the use of the Fourier Transform Infrared Spectroscopy (FTIR) technique. Eventually, the knowledge gained with the validated CFD code and experimental data will be utilized to design and build a 2 kW direct methanol fuel cell stack.

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Graduate Fellowship News

Our hats go off to Mrs. Cynthia Shirey. She is the first Penn State GATE Fellow to complete the GATE curriculum and graduate. Mrs. Shirey received her M.S. in Engineering Mechanics in May 2000. Her thesis, advised by GATE Professor Charles E. Bakis, Department of Engineering Science and Mechanics, concerned the fatigue behavior of composite flywheel materials. Mrs. Shirey began work at Beacon Power, Woburn, Massachusettes, in June 2000. Beacon Power is a pre-IPO company that designs and markets uninterruptible power supplies consisting of composite flywheels.

Mr. Duane Dudeck, another May graduate received his Master of Science in Mechanical Engineering and the GATE certificate. His thesis topic was the development of a hybrid electric vehicle drivetrain. Mr. Dudeck has accepted a job with Northrop Grumman in Baltimore, Maryland, a commercial/defense aerospace and military contractor.

To date four graduate students have accepted GATE Fellowship offers for the 2000/2001 academic year. Returning to the GATE program this year is Mr. Steven Boslet, returning to the Electro-Chemical Engine Lab with Dr. Chao-Yang Wang. Students joining the GATE Fellowship program this year are Mr. Russell Owens, Mr. Douglas Piccard, and Mr. Sean Spindler-Ranta.

In addition to the GATE Fellowships, the Penn State GATE Center is offering eleven fellowships in conjunction with the National Science Foundation (NSF) GK-12 Teaching Fellows on the M³ Educational Highway. The students accepting these fellowships will have the opportunity to use the hybrid-electric vehicle platform to interest children in grades K-12 in science, math, engineering, and technology. To date, three students have accepted (Mr. Oliver Finckh, Ms. Sara Inman, and Mr. James Musser) offers for the upcoming academic year.

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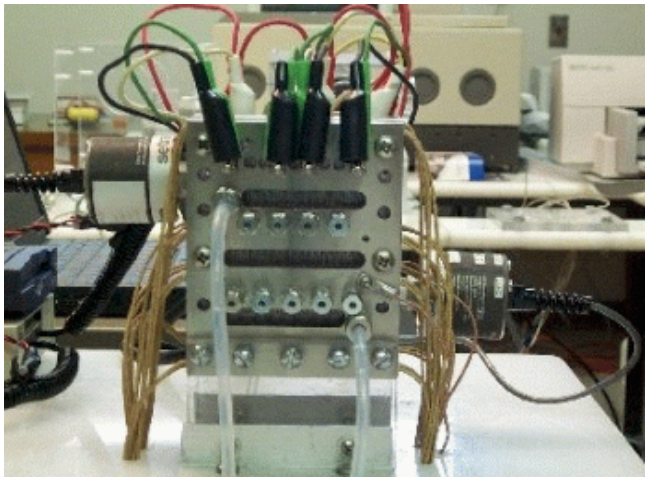
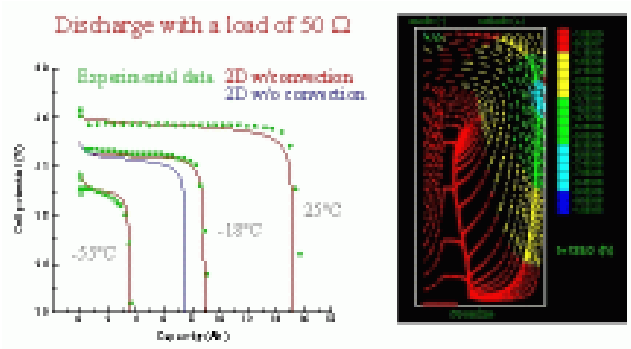


Close-up of the Windowed Direct Methanol Fuel Cell

Yet another recent success story is a two-dimensional model which simulates discharge of a primary lithium/thionyl chloride battery. An accurate predictive tool for the Li/$SOCl_2$ battery is very critical since the battery is widely used for firing missiles, as well as in the aerospace industry. The model accounts not only for transport of species and charge but also for the electrode porosity variations and electrolyte flow induced by volume reduction upon electrochemical reactions. Numerical simulations are performed using a finite volume method of computational fluid dynamics. The predicted discharge curves for various temperatures were compared to experimental data with excellent agreement. Moreover, the simulated results in conjunction with computer visualization and animation techniques reveal that cell performance in the parametric range of interest is limited by pore plugging at the front side of the cathode as a result of LiCl precipitation. Detailed two-dimensional flow simulation also shows that the electrolyte flow is predominantly in the horizontal direction from the separator to the cathode.



Visualizing Electrolyte Flow in a Li/SOCl2 Battery

"With the ever-increasing need for accurate computer simulation and a wide range of experimental testing, the future of the Electrochemical Engine Laboratory is bright," says Dr. Wang. "The EC Engine Laboratory is well equipped to handle a wide variety of different applications, on both a fundamental and application-based level. We have the facilities and expertise in place to quickly conduct useful computational modeling and experimental studies on a range of electrochemical power systems, particularly those for transportation applications. This is an exciting field to be in right now, and we look forward enthusiastically to growing and adapting to the ever-changing needs of our sponsors." More information on this and other ongoing projects at the Electrochemical Engine Laboratory can be found at: http://mtrl1.me.psu.edu. ■

FutureTruck 2000

Based on the observations made by General Motor's (GM's) representatives during site visits, Penn State was chosen as the location to film activities for FutureTruck 2000 promotional purposes. An honorable distinction for the team.

The Penn State FutureTruck 2000 Team held an Open House on April 28th to showcase the Powerlion. Local media were on hand to record the event. Congressman Peterson was in attendance.

A final report describing the team's efforts over the past year was completed June 1st. The Powerlion uses a 4.0 liter Turbo-Direct-Injection (TDI) diesel engine coupled to a 100 kW alternator capable of low- and high-speed operation. Its energy storage system combines batteries and ultracapacitors to achieve increased sstorage efficiency. An embedded controller executes advanced algorithms to optimize power generation, energy storage, and drivetrain function. The 210 kW electric drive system has two speeds and enhanced cooling features to provide sustained towing capacity. The report proceeds to detail the requirements of the FutureTruck competition as well as the methodology used to arrive at the final configuration of the vehicle.

The Penn State team spent quite a few late nights in the garage next to the Pennsylvania Transportation Institute (PTI) preparing for the FutureTruck 2000 competition held June 11-16 at the GM proving grounds in Arizona. Although complications with the controllers prevented the Powerlion from finishing in the top 10 this year, the team is confident that they will be the team to beat at next year's competition.

Meet the People

The Director of the Electrochemical Engine Laboratory, Dr. Chao-Yang Wang, is Associate Professor of Mechanical Engineering and Associate Director of the GATE Center for Advanced Energy Storage. Dr. Wang received his Ph.D. from the University of Iowa in 1994. After working as an assistant professor at the University of Hawaii, he joined the faculty at Penn State in 1997. Dr. Wang has had extensive experience in the areas of batteries and fuel cells, multiphase transport, and mathematical modeling.

Dr. Matthew Mench joined the Penn State GATE Center for Advanced Energy Storage in May as Associate Director of the Electrochemical Engine Laboratory. Before receiving his Ph.D. from Penn State this spring, Dr. Mench was a NASA Graduate Student Research Program Fellow, and completed a period of study at NASA White Sands Test Facility in Las Cruces, New Mexico. His educational background includes research on combustion, chemical kinetics and solid propellant stability behavior. He has also taught undergraduate fluid mechanics and thermodynamics courses at Penn State.

A key addition to the laboratory team is Dr. Venkat Srinivasan, an electrochemist graduated from the Center for Electrochemical Engineering at the University of South Carolina. Dr. Srinivasan has done extensive research in experimental characterization of electrochemical energy systems such as Ni-H_2, lithium batteries and carbon/metal-oxide based capacitors

Recent Publications/Presentations

G.G. Portnov and C.E. Bakis, ***Estimation of Limit Strains in Disk-Type FlywheelsMade of a Compliant Elastomeric Matrix Composite Undergoing Radial Creep***, Mechanics of Composite Materials, 36:87-94 (2000).

R.P. Emerson and C.E. Bakis, ***Viscoelastic Model of Composite Flywheels***, Proceedings 45th SAMPE Symposium a nd Exhibition, Society for the Advancement of Materials and Process Engineering, Covina, CA, 2000.

C.E. Bakis and M.W. Orlet, ***Tensile Behavior of Filament-Wound Glass Reinforced Elastomeric Tubes***, Proceedings 45th SAMPE Symposium a nd Exhibition, Society for the Advancement of Materials and Process Engineering, Covina, CA, 2000.

C.L. Shirey and C.E. Bakis, ***Effect of Vacuum Conditioning on the Axial and Transverse Tensile Properties of Filament Wond Composites***, CMTC-2000-2, Composites Manufacturing Technology Center, PSU, University Park, Pa., May, 2000.

G.Q. Wang and C.Y. Wang, ***Direct Numerical Simulation of Mass Transport and Electrochemical Reaction in a Lithium-Ion Cell***, presented at 197th Electromechanical Society Meeting, Toronto, May 2000.

Z.H. Wang and C.Y. Wang, ***Two-Phase Transport in the Interdigitated Air Cathode of Proton Exchange Membrane Fuel Cells***, presented at 197th Electromechanical Society Meeting, Toronto, May 2000.

C.Y. Wang, ***Transport Phenomena in Proton Exchange Membrane Fuel Cells***, in Proceedings of International Symposium on Energy Engineering, Hong Kong, January 2000.

J. Anstrom et al., ***Penn State Future Truck 2000 Design Report***, Society of Automotive Engineers, Warrendale, Pa., June 2000.

D. Streit et al., ***Graduate Automotive Technology Education in Energy Storage Systems--GATE Penn State***, presented at the Annual ASEE Conference, St. Louis, Missouri, June 2000.

Acknowledgements

The team at the Electrochemical Engine Laboratory would like to sincerely thank the sponsors of various programs, including Arbin Instruments, the Defense Advanced Research Projects Agency (DARPA), Electrosource, Inc., Eveready Battery Company, the Hawaii Electric Vehicle Demonstration Project (HEVDP), the Jet Propulsion Laboratory (JPL), the Mid-Atlantic Regional Consortium for Advanced Vehicles (MARCAV), National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), Sandia National Laboratories, the Ford Motor Company, the Pennsylvania Department of Environmental Protection, the U.S. Department of Energy (DOE), and the U.S. Department of Transportation (DOT).

Calendar of Events

2nd Annual Meeting of the Penn State GATE Advisory Board to be held at the Pennsylvania Transportation Institute, University Park, PA, July 19, 2000.

3rd Annual Transportation Research Conference to be held at the Pennsylvania Transportation Institute, University Park, PA July 20, 2000.

In-Vehicle Testing and Computer Modeling of Electric Vehicle Batteries, to be presented by Chao-Yang Wang at the 17th International Electric Vehicle Symposium, Montreal, October 2000.

Graduate Fellowships Available

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GATE Fellowship Applications for the 2000/2001 academic year are still being accepted. In addition, several fellowships are still available for the NSF project. Please visit the GATE website for details on how to apply for either of these fellowship opportunities.

Information

For more information on Penn State's GATE Center, please contact the director, Donald Streit, at

Pennsylvania Transportation Institute
201 Transportation Research Building
University Park, PA 16802-4710
voice: 814-865-1894
fax: 814-865-3039
e-mail: dstreit@psu.edu
website: http://www.vss.psu.edu/gate/