Using neutron imaging to improve energy efficiency

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Neutron scientists at Oak Ridge National Laboratory (ORNL) are partnering with industry to enhance engine and commercial cooling technologies in hopes of making improvements that will optimize fuel and energy efficiency.

Hassina Bilheux, a physicist and a neutron imaging scientist at ORNL, uses beam line CG-1D at the High Flux Isotope Reactor (HFIR) to image automobile engine system components, two-phase fluid components in commercial cooling systems, and electrodes used for lithium batteries.

Michael Cameron of DuPont, former chair of the SNS and HFIR Users Group, has cited applications in the auto industry and in transportation generally as highly promising for such partnerships.

Neutron imaging is just taking off at ORNL; there is currently no instrument at the laboratory devoted exclusively to it. Bilheux, the lead for developing ORNL's neutron imaging capabilities, works on industrial imaging projects with colleagues at ORNL and in industry.

CG-1D is a new facility developed in 2009 by Lee Robertson and his team in the Neutron Facilities Development Division. The CG-1 beam line runs off HFIR's HB4 Cold Source (a cold source provides neutrons cooled to a low temperature to make them move more slowly). "These are not imaging beam lines," said Bilheux. "They are not optimized for imaging. But we have been very successful since we started in December

2009 preparing CG1-D for imaging." When the neighboring beam CG 1-C becomes operational, Bilheux hopes to add it to the suite of imaging capabilities.

The CG-1D is a chopped beam instrument (i.e., neutrons are chopped into small packets, which allows their energy to be determined) and 1C is monochromatic (i.e., all the neutrons used in a single exposure have the same energy). Bilheux hopes eventually to bring neutron imaging capabilities to the Spallation Neutron Source (SNS), where she can better and more cost-efficiently select the energy of the neutrons. SNS, she says, has a wide range of energies that makes it possible to image thick biological tissues. (That type of work cannot be done at HFIR, where the neutrons would be scattered by the high hydrogen content in tissues.) The higher the energy, the deeper the penetration, and the more researchers are able to see.

"One of the goals is to bring the science to SNS, so we can develop a partnership with the medical community to explore neutron imaging capabilities for biological tissues, and eventually to work with medical doctors, such as ORNL M.D./Ph.D. Dr. Trent Nichols, and oncologists to look at tumor tissues. We are truly pioneering a new field and this is a unique time for all of us. I am very excited about all the progress we have made at CG1-D."

That progress is visible now in a series of industrial research projects already afoot or in the planning stage. Two of the projects under way involve vehicle technologies: producing 2- and 3-dimensional images of exhaust gas recirculation (EGR) coolers and images of diesel particulate filters (DPFs), which remove the black soot cloud so often associated with diesel exhaust. In both cases, the goal is to improve fuel efficiency and, in the case of the DPF project, to consider the emissions and materials impacts of the introduction of biofuels.

To take measurements, researchers set a sample in the beam and use a detector behind it to collect the neutrons that are transmitted, literally taking shadow pictures of the sample. "Neutrons are especially great for engineering applications because they don't see metals very well but are efficient at seeing hydrogen-rich fluids," Bilheux explained.

Neutron imaging is noninvasive and nondestructive: the sample-whether the engine of a car, a battery, or a component from an industrial cooling system-need not be cut into small sections for neutron imaging as it might for traditional microscopy.

In the EGR coolers project, the researchers, led by Michael Lance of ORNL's Materials Science and Technology Division, measured coolers from 10 participating companies "This is thrilling," Bilheux said. "I think this is a great success story for NScD."

Neutron imaging measures how the hydrocarbon (enriched particulate matter) is deposited within an EGR cooler that shows significant clogging. The role of the coolers is to lower the oxygen content and the combustion temperatures, thereby reducing the formation of NOx (nitrogen oxides) in the cylinder. Thanks to the imaging, the researchers can measure the thickness and hydrocarbon content of the deposit and come to understand the spatial and time dynamics of particulate matter deposition. In future measurements, tomography will be used to image complete, intact coolers in three dimensions.

A second vehicle project concerns how soot and ash build up in the DPF of a diesel-powered vehicle, and the impact of fuel type. DPFs were developed to remove the particulates (primarily soot) once common in diesel engine exhaust. Bilheux is working with Charles Finney, Andrea Strzelec (now at Pacific Northwest National Lab), and Todd Toops at the Fuels, Engines, and Emissions Research Center (FEERC) at ORNL's National Transportation Research Center. At FEERC, the researchers use diesel engines operated on dynamometer platforms to introduce particulates to the DPF. This enables the study to occur on real engines under industry-relevant conditions; additionally, field-aged samples have been provided to the FEERC researchers from industrial partners.

The work began with measurements of DPFs at different soot and ash loadings in early March. As the neutrons are able to penetrate the ceramic filter, they can take measurements of the hydrocarbon-rich particulates (soot) and metal-oxide-based ash. Although these materials are not necessarily highly sensitive to neutrons, they have a high surface area and are very hydroscopic (readily attracting moisture). The adsorbed water allows detection by neutrons. Neutron tomography is used to view and measure the thickness of the soot in the channels and the location of ash deposits. Ash, mostly from lubricant additives, affects engine efficiency by clogging the filter and increasing the backpressure on the engine and curtails filter life.

Manufacturers continually strive to create DPF control strategies to maximize the energy efficiency of the combined engine and aftertreatment system; the neutron tomography data further the understanding of the DPF technology to aid the optimization process.

The work is supported by DOE's Office of Energy Efficiency and Renewable Energy. The researchers hope to improve fuel efficiency and to clarify the impacts of biofuels on emissions and aftertreatment systems.

A third project entails devising strategies to improve the prediction of phase-change heat exchange, another longstanding industrial challenge. Phase-change heat exchangers, such as evaporators and condensers, are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, and natural gas processing. The performance of such equipment is difficult to predict, and testing is expensive, so components are routinely oversized to ensure they perform as required. Uncertainty about component performance prevents the optimization of system efficiencies, resulting in wasted materials and energy.

The collaboration includes researchers from the United Technologies Research Center, the research arm of United Technologies Corporation, which works on long-range technological problems afflicting U.S. industry.

"The commercial heat exchanger project is huge," Bilheux said. "When you have a fluid with vapor and liquid phases existing together in a heat exchanger, the cooling capability of that unit depends on the characteristics of the liquid-vapor interface. If we can visualize what is happening with the heat exchangers, it will give them data for model validation under true working conditions."

Heat exchangers have two-phase flow, a vapor phase and a liquid phase. These phases do not necessarily travel at the same velocity, and in many cases, the phases may be separated by the forces acting on them. These effects can exert a strong influence on the thermodynamic performance of a component and must be understood if accurate predictive models are to be developed. Using neutrons, researchers can look inside the components under operating temperature, pressure, and heat flux conditions and see where the vapor and the liquid exist. Data of this nature are very difficult to obtain using other test methods, such as optical measurements, because adding transparent walls to the component will affect the process to be measured. Neutron imaging allows direct measurement of interface characteristics with the correct wall materials and under the right thermodynamic conditions.

Finally, Bilheux is engaged with computational scientist Sreekanth Pannala and battery expert Jagjit Nanda at ORNL, as well as industry partners, to measure lithium transport inside complex electrodes.

"This is an important research area for DOE and involves substantial participation by industrial partners," Bilheux said. Battery storage devices have excellent energy and power-to-weight ratios and are now the power source of choice for cell phones, cameras, and notebook computers. Lithium batteries are also used extensively in biomedical and military applications, and prospects are good for the use of lithium batteries in transportation in the future.

Batteries are being studied in collaboration with Ford and GM energy storage researchers and with other cell manufacturing companies. Lithium cells in several forms- DD, cylindrical, prismatic-are being studied via neutron imaging. Scientists working at the Oak Ridge Leadership Computing Facility will plug the imaging data into their computer models of batteries to validate and refine them. The experimental data enable computational scientists to create battery models that accurately reflect what goes on in the experiments.

The researchers, who have LDRD funding, began their measurements in March 2010. They hope to reach 50 micron resolution in fall 2010, which will enable them to look at electrolyte levels and get a feel for what is going on inside a battery as they cycle it, said Bilheux.

"We want to look at the degradation and the transport of the lithium, and to give feedback for the computational models on how to build an accurate model of a lithium battery. They want to know, 'if we change the materials, how does it affect transport?' and they want to do it in situ to get a real idea of what is happening inside."

Bilheux is exactly where she wants to be. "The SNS and HFIR, to me are like a train, and it is on a fast pace, and you just jump on it and go with the flow!"

She has her eye on other fields as well, hoping in the future to image ancient artifacts for the Smithsonian Museum.

Provided by Oak Ridge National Laboratory

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