THIS MONTH: CORROSION CONTROL AND THE ENVIRONMENT

JANUARY 2011

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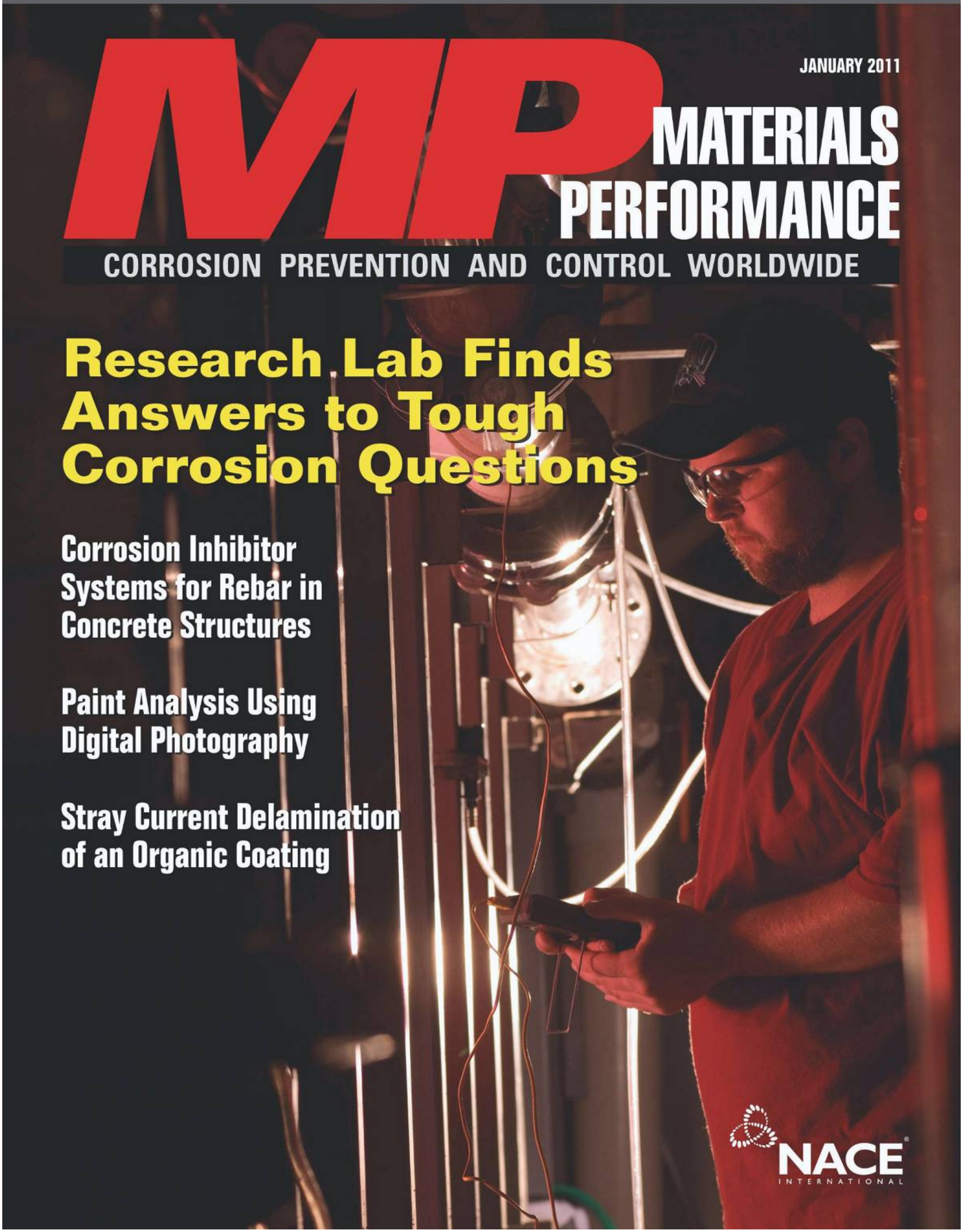

Research Lab Finds Answers to Tough Corrosion Questions

Corrosion Inhibitor Systems for Rebar in Concrete Structures

Paint Analysis Using Digital Photography

Stray Current Delamination of an Organic Coating

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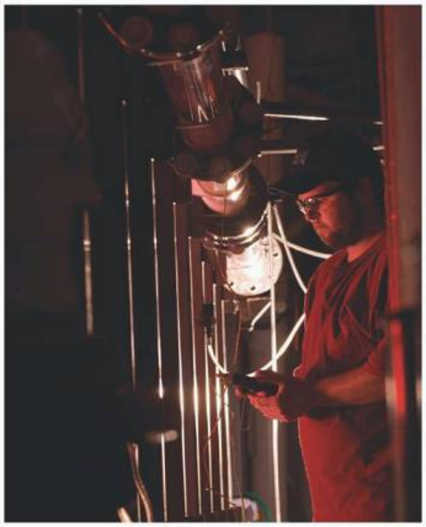
About the Cover

Former graduate student Joshua Addis is monitoring the operation of a two-phase, erosion-corrosion flow loop at Ohio University's Institute for Corrosion and Multiphase Technology. For the past 20 years, companies battling internal corrosion of oil and gas wells, pipelines, and associated structures have sought assistance from this corrosion research facility, which utilizes nine large-scale multiphase corrosion flow loops to mimic corrosive conditions in the field. Photo by Rick Fatica, Ohio University.



NACE INTERNATIONAL
THE CORROSION SOCIETY

Ohio University's Research Facility Tackles Industry's Corrosion Challenges

Institute for Corrosion and Multiphase Technology Searches for Answers to Tough Corrosion Questions

Kathy Riggs Larsen,
Associate Editor

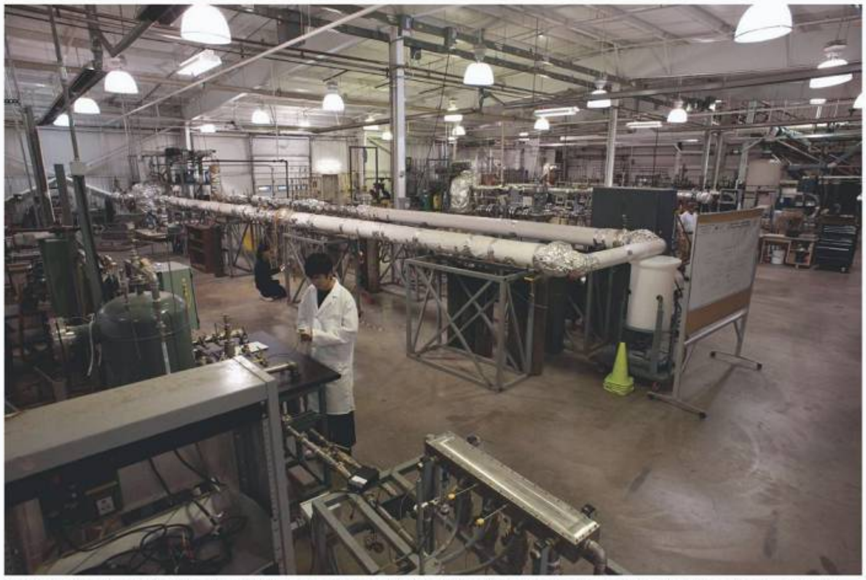
Bruce Brown (left), ICMT associate director for operations, and Ph.D. student Kee Kok Eng discuss the operation of the inclinable, multiphase flow rig, which has the capability of operating at inclinations of up to 90 degrees. Photo copyright Gary J. Kirksey 2010.

Helping industry battle corrosion is nothing new for the students and staff at the Institute for Corrosion and Multiphase Technology (ICMT). For the past 20 years, oil companies plagued with internal corrosion of oil and gas wells, pipelines, and associated structures have sought assistance from this corrosion research facility, which is part of Ohio University (OU) in Athens, Ohio (not to be confused with Ohio State University in Columbus, Ohio). Demand for ICMT's corrosion research is still strong today, as companies from several major industries continue to pursue better understanding and novel solutions to the degradation problems that threaten the integrity of their facilities.

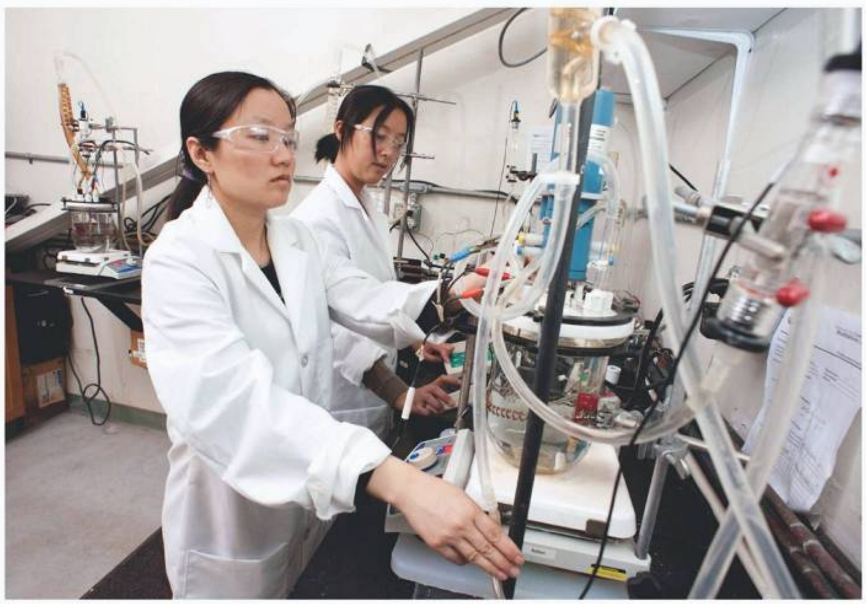
"Although carbon steel (CS) is not the most corrosion-resistant material available, it is widely used in industry because of its availability and affordability," says Srdjan Nešić, FNACE and Russ Professor in the Department of Chemical and Biomolecular Engineering at OU's Russ College of Engineering and Technology. Using only corrosion-resistant alloys to construct huge facilities would be an enormous financial outlay and often these alloys are just not obtainable in the amounts that are needed, he says, adding that many projects would not be developed if using these alloys was the only option. Given that use of CS will continue, ensuring the survivability of CS components is crucial. The challenge for industry, as well as the researchers at ICMT, is to understand how and why CS corrosion is happening, how severe it is, and what to do about it.

"What is unique about our research institute is that our work is directly driven by specific problems encountered by the industry," Nešić explains. Companies come to ICMT when they feel they need better understanding and assistance with a particular corrosion problem seen in the field. "Most of our projects—and 97% of our annual budget—come directly from the grants provided by private companies," he notes.

Since ICMT's first research project, sponsored by ARCO in 1989, the institute has worked with many of the world's top oil, gas, chemical, and engineering companies to better understand and mitigate CS corrosion that is caused primarily by water-soluble gases, such as carbon dioxide (CO_2) and hydrogen sulfide (H_2S), found in oil and gas streams. Over the years, ICMT has grown into an established research center for investigating internal CO_2 and H_2S corrosion of CS that is related to multiphase flow in oil and gas lines. What this means, in layman's terms, is that researchers study, identify, and attempt to understand the characteristics and behavior of multiple phases (oil, gas, water, and sand) flowing together through a CS pipe that cause interior line corrosion when acid gases such as CO_2 and H_2S are present. ICMT is now the largest facility of its kind in the world, with a building and research-related equipment worth over $15 million and an annual research budget of $2.5 million. To be a member of one of ICMT's research projects, sponsors pay anywhere from tens to hundreds of thousands of dollars per year, and research requests are received from companies across the globe, including the United States, Canada, United Kingdom, France, The Netherlands, Italy, Brazil, Argentina, Saudi Arabia, United Arab Emirates, Japan, China, Malaysia, Thailand, and Australia. Currently ICMT is working with approximately two dozen companies on seven major long-term projects.

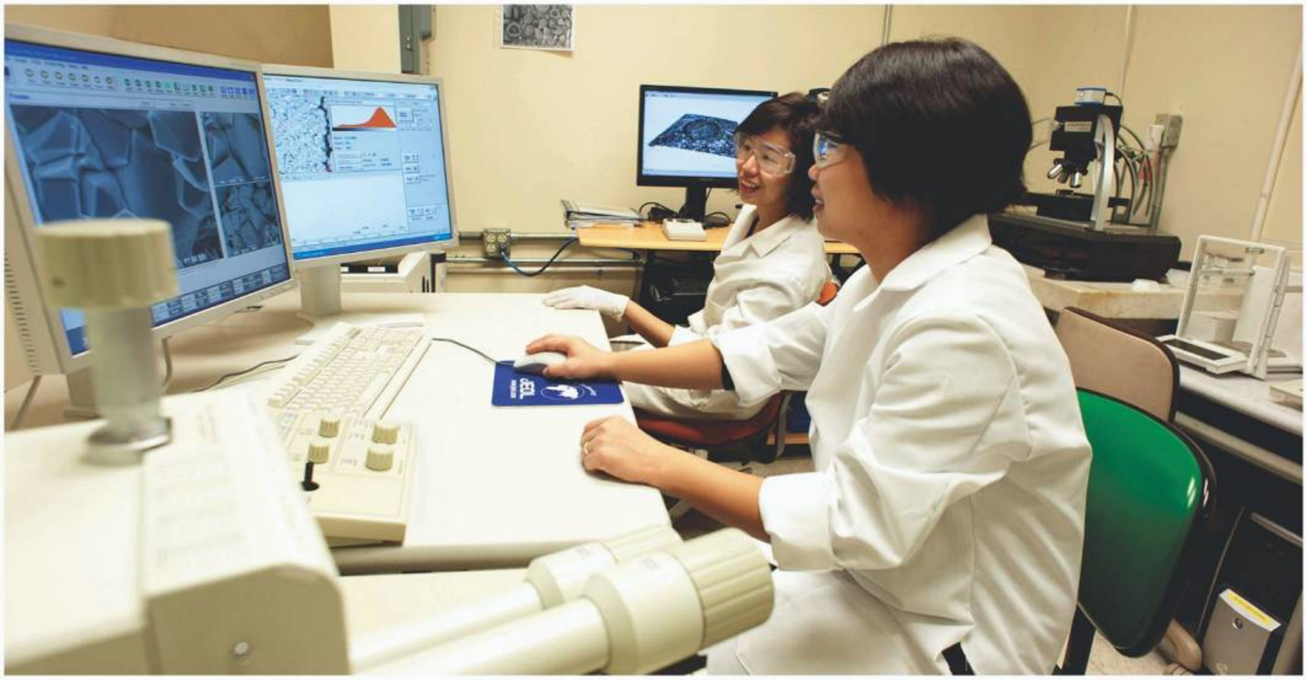


OU graduate students check the operation of the 30-m long wet gas corrosion flow loop, which is designed to study the corrosion effects of operating parameters on CS under dewing conditions during the transportation of wet gas. Photo copyright Gary J. Kirksey 2010.



Graduate students Xin Gao (front) and Jin Huang perform experiments in the ICMT's glass cell laboratory. Photo copyright Gary J. Kirksey 2010.

ICMT emerged from a former National Science Foundation (NSF) Industry University Cooperative Research Center (IUCRC) for corrosion. During the past decade, ICMT has increased its research activities almost tenfold, as indicated by the rise in the number of projects, students, publications, and research funding. Nešić has served as its director since 2002.



Ph.D. students Yang Yang (front) and Kod Pojtanabuntoeng analyze the surface of a corroded CS sample using a scanning electron microscope (SEM) and an optical infinite focus microscope (IFM). Photo copyright Gary J. Kirksey 2010.

Ongoing Corrosion Research

While some of ICMT's projects are funded by individual companies and an occasional government grant, typically the institute's research is financed by Joint Industry Projects (JIPs), where several companies experiencing similar corrosion issues will join together and pool their resources to launch a much larger research undertaking. JIPs typically last one to three years. Specific research topics are determined by practical problems experienced by the industrial partners, and the corresponding research projects are directed by an advisory board comprised of representatives from the JIPs' member companies.

Nešić comments that most of the research projects at ICMT have traditionally focused on the upstream sector of the oil and gas industry, where internal corrosion issues arise when aggressive media, such as water with dissolved CO_2, H_2S, organic acids, bacteria, etc., accompany crude oil and gas that is piped to processing facilities from underground or subsea oil and gas fields. The ICMT's largest upstream JIP has over 20 sponsoring companies and covers some of the most common generic corrosion problems seen in the industry, such as localized CO_2 corrosion and sour corrosion (corrosion in the presence of H_2S).

The institute's corrosion research related to the oil and gas industry's downstream sector primarily focuses on crude oil refining. Following seven years of proprietary developments, the ICMT will start a new three-year JIP in 2011 that is related to naphthenic acid corrosion, which refers to attack seen in the absence of water when processing acid-containing crudes at very high temperatures.

A few years ago a new group of environmentally oriented research projects was initiated at ICMT. Directed toward the power industry, the projects are related to carbon sequestration at fossil fuel-fired power plants, where CO_2 is separated from the flue gas and deposited underground rather than being released into the atmosphere. Nešić notes that this type of work is a natural extension of the CO_2 corrosion research being done for the oil and gas industry. "We are building on our strengths and gearing up to answer material-related questions that arise from transportation of CO_2 and whatever else comes with it from the flue gases," he says. One project in particular focuses on potential corrosion issues in a process that uses amines to separate the CO_2 from the flue gas stream before the flue gas is exhausted into the atmosphere. The industrial sponsor selected ICMT to do experiments and research so that the most appropriate, corrosion-resistant materials for construction of these process facilities could be selected, Nešić says. He anticipates that corrosion research related to CO_2 sequestration, transportation, and injection will become progressively more important as these new technologies move forward.

A more complete list of ICMT's projects can be found on its Web site, www.corrosioncenter.org.

Simulating Environments Found in the Field

"The studies we do are carried out in facilities that mimic, to the largest possible extent, the conditions as they are in the field," Nešić comments. He notes that the requirements to simulate these environments include the ability to reach very high pressures and high temperatures, and to set up multiphase flow with very specific chemistry (i.e., cocurrent liquid and gas streams that can contain hydrocarbons, CO_2, H_2S, organic acids, etc.). "We pride ourselves on being able to generate the right kind of environment in the laboratory that is close to what our sponsors are experiencing in the field," he says. "That is our strength."

Nešić emphasizes that these types of conditions can't always be recreated in small-scale glass equipment or autoclaves. To replicate various corrosive environments, the ICMT laboratory (which he describes as being about half the size of an American football field with a four-story tall bay area) utilizes nine large-scale multiphase corrosion flow loops with 4-in (102-mm) inside diameter pipe and lengths up to 40 m. "Size does make a difference here," he says, explaining that the large flow loops are necessary to realistically reproduce the behavior of multiple fluids mixing and flowing over a distance, which just can't be done in small pipes or autoclaves.

One of the most advanced flow loops is dedicated to corrosion experimentation with H_2S, which is a highly toxic, very water soluble, and extremely corrosive gas. This flow loop is located inside its own isolated room for safety as well as better control of experiments involving hazardous gases. Due to stress corrosion cracking concerns, this flow loop is constructed of Hastelloy© C-276 (UNS N10276), a material that is impervious to H_2S attack, Nešić explains. "Of course, actual pipelines are made of mild steel (CS), but we can't use such a material to build our research facility because it would corrode away in a matter of years or sometimes even faster," he says. Researchers insert CS sample coupons into the flow loop, expose them to the simulated aggressive environment, then extract them after a period of time and observe the corrosion effects.

The ICMT laboratory houses three additional high-pressure (up to 7,000 kPa), high-temperature (up to 120 °C) corrosion flow loops, constructed of Type 316 stainless steel (UNS S31600). One of them is mounted on a rig that is capable of operating at an incline of up to 90 degrees to replicate flow in vertical lines. The two other high-pressure flow loops, 25 and 30-m long, include a transparent section for flow visualization and are currently used for studying corrosion in wet gas flow.

Low-pressure flow loops include an erosion-corrosion multiphase flow loop, which is an 18-m long, 100-mm diameter line that simulates multiphase flow and steel degradation in the presence of corrosive species and entrained solids; and a flow loop built to simulate corrosion of lines at road and river crossings and in lines crossing hilly terrain. Additionally, a part of the laboratory has been adapted to cater to the needs of research on the naphthenic acid corrosion seen in refineries.

Because the term "laboratory" often brings to mind a room with instruments and glass beakers, Nešić stresses that ICMT has that as well—a glass cell laboratory that allows experiments to be performed on a small scale and much more quickly and economically than when conducted in the large multiphase flow loops. Not only is the glass cell lab used to quickly identify corrosion issues, it provides researchers with the means to calibrate instruments, perfect procedures, and troubleshoot issues encountered with the large-scale equipment. It is also utilized as a training facility for students preparing to administer experiments in the high-pressure, high-temperature multiphase flow loops. A number of high-pressure, high-temperature autoclaves (in sizes ranging from 2 to 20 L) as well as a few small-scale flow loops bridge the gap between the glass cell laboratory and the large multiphase flow loops.

Researchers and Results

About 25 OU graduate students and another 25 staff members, including professors, engineers, technicians, and administrators, execute ICMT research projects. Virtually all research projects are conducted by graduate students, who are supervised by a project leader on a daily basis and guided over the longer term by one or more research advisers who are typically OU professors. Frequently a mentor from industry, who may be appointed as an adjunct professor, is also involved in student advising. Progress on research projects is reported by students every six months at semi-annual advisory board meetings.

Generally, the research projects at ICMT aim to increase the body of knowledge and understanding of internal pipeline corrosion experienced in the field by redefining and recreating practical problems through theory and experimentation. According to Nešić, once the knowledge about any given problem is mature—that is, when the researchers understand and can explain how the corrosion process happens and have obtained supporting experimental evidence—then a mathematical and computer model are constructed that capture this knowledge and help the corrosion engineers in the industry to explain or even predict a particular corrosion event in the field. This software is a tool that is becoming an increasingly important deliverable to research sponsors, Nešić says, as it is a practical repository of knowledge generated on the project as well as a hands-on means of utilizing it.

Typically the essence of the work is published in scientific journals. Nešić acknowledges, however, that a portion of the research results sponsored by the private sector remains confidential. While the science behind the research—the basic theoretical principles and findings—is disclosed via thesis, conference, and journal papers, the technological details are only revealed to the research sponsors. "This way we span the two requirements, to publish and to provide confidentiality. It works well," he says.

Editor's note: A paper based on an ICMT research project, "A Mechanistic Model of Uniform Hydrogen Sulfide/Carbon Dioxide Corrosion of Mild Steel," authored by ICMT alumna Wei Sun along with Srdjan Nešić, was selected to receive NACE International's 2011 CORROSION Best Paper Award, which will be presented at CORROSION 2011 in Houston, Texas in March. MP