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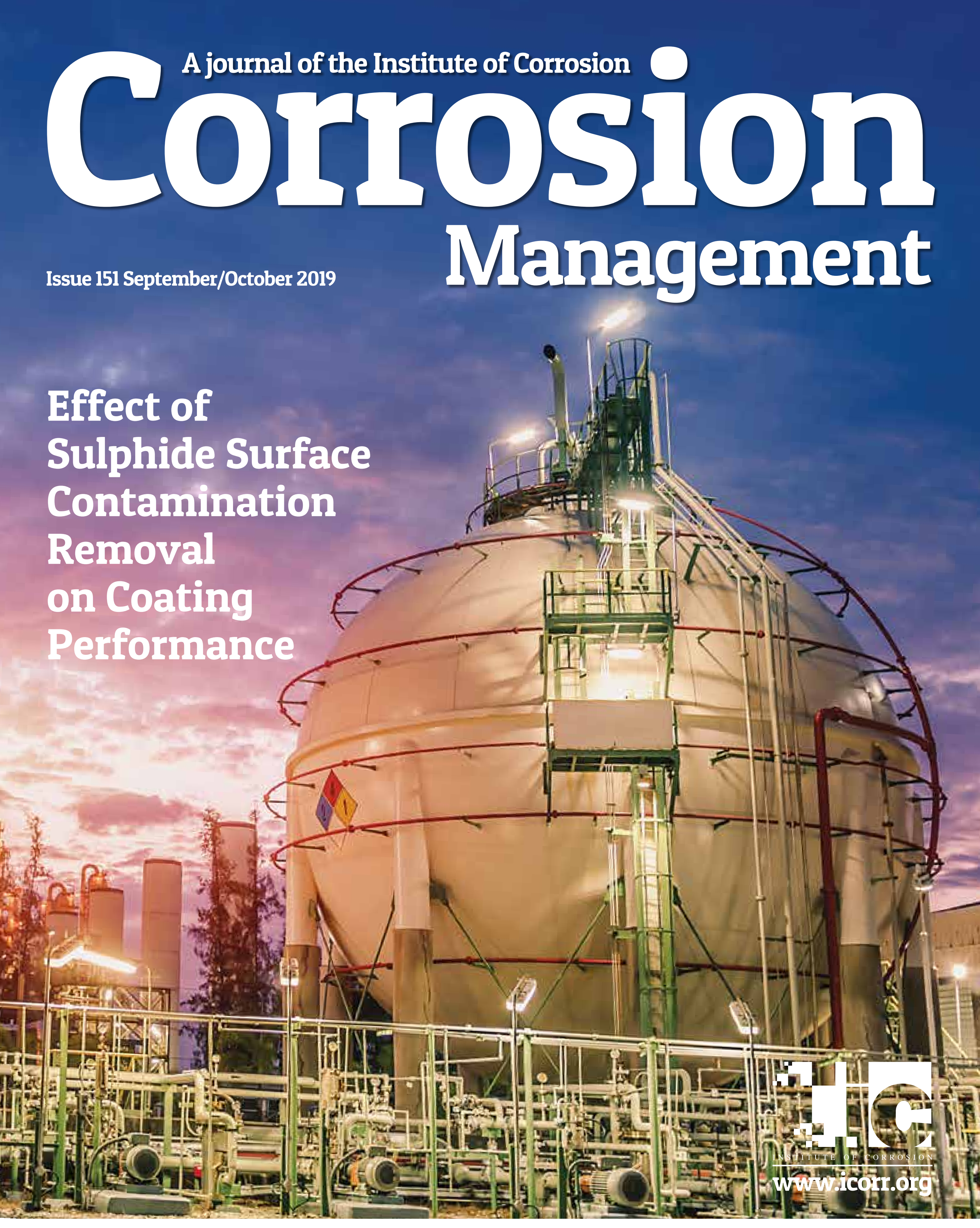

Effect of Sulphide Surface Contamination Removal on Coating Performance

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Using impressed current cathodic protection in remote and off-grid sites

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Cathodic protection is required by law in many countries for applications including gas pipelines, well head casings, tanks, vessels and marine structures, such as jetties. Furthermore, remote and off-grid sites face the challenge of providing reliable and low-cost power. This article describes the relative merits of impressed current cathodic protection (ICCP) when powered by mains, diesel generators and solar or wind powered systems with batteries.

ICCP is one of the techniques used to control corrosion of steel structures, and is used widely in the oil and gas, marine and ports industries, and offshore wind farms, where it protects assets such as underground or buried pipelines from natural deterioration. As a result, it protects safety and process continuity, as well as the environment, as it reduces the risk of leaks from oil and gas pipelines and infrastructure.

Overall, it provides confidence and efficiency for operators who can apply ICCP to provide a constant trace current to slow down the rate of corrosion.

This is particularly important for operators of remote and off-grid sites, where it can be challenging to schedule a visit by a qualified technician for inspection and maintenance of vital assets.

How impressed current cathodic protection works

Four components are needed for corrosion to take place through a natural galvanic reaction: a cathode, anode, electrolyte and an electrical pathway. ICCP works on the principle of overcoming the galvanic current with an opposing current.

In a typical ICCP system, a transformer/rectifier draws power from the mains and converts it from AC to DC. It then provides a constant trickle of direct current via anodes in the ground, with current flowing towards the structure to be protected. As a result, this system can prevent the natural oxidation of steel structures.

Depending on the level of current applied, ICCP will slow the rate of corrosion. Some systems can even extend asset life indefinitely as they reduce the rate of corrosion to almost zero. A single system can protect a length of approximately 50km of pipeline in a desert (where soil resistivity and moisture levels are low) but this can drop to 100 metres for structures immersed in sea water.

Installations that require protection include pipelines (it is, in fact, a legal requirement in many countries for gas lines in particular). It is also applicable for tanks, vessels, well casings, jetties and any other submerged metallic structure.

For many installations, a system can be down for several months without posing a major risk, but the more constant and reliable the supply of current, the better.

Some of the different methods of powering ICCP include:

Mains power: Around 90 percent of ICCP systems are powered by the grid. It provides high reliability, known and constant current and voltage, and low risk of outages. ICCP systems require relatively low power compared with other industrial loads such as motors for pumping systems. However, it is only possible to specify a mains-fed ICCP system at sites where grid infrastructure exists, or where a grid connection can be delivered for a modest investment that is equivalent, or lower, than the cost of other power solutions.

Diesel genset: This is the traditional option for remote sites that do not have access to the grid and uses a diesel generator to provide power, either intermittently or constantly. This solution is relatively inexpensive if a grid connection is not available. However, such sites have high operational costs due to the need for a technician to visit regularly to refuel, inspect and maintain the genset. In addition, when specialised maintenance is needed, the operator will need to call on the services of a qualified technician to supply and fit spare parts, etc., and this can be a logistical challenge in some locations.

Renewable energy: This option uses solar photovoltaic panels (PV) or wind turbines to generate power to support the ICCP. Because renewable energy does not consume fuel, it has the advantage of having low operating costs that offset the relatively high installation cost. It is best suited to sites that are rich in renewable energy.

PV panels are well established in this application, having been used for 20-30 years in ICCP installations. They have the additional benefit that they generate DC power so there's no need for a rectifier to convert AC to DC.

However, when the sun doesn't shine or the wind doesn't blow, power drops off and corrosion will restart, which has the potential to increase risk in the long term. As a result, many operators integrate a battery system to store renewable energy and release it when needed. For a solar-powered system, the battery will charge during the day and release energy overnight and on overcast days – and it's a similar principle for wind-powered systems, which charge the batteries on windy days. Typically the cost of adding a battery is significantly less than the value of the infrastructure that the ICCP system is protecting so it is well worth the investment.

However, it's important to select the battery carefully as not all batteries are tough enough to provide reliable service in a remote off-grid site, where temperatures can vary widely and impact performance and lifetime.

All of these methods can be compared with galvanic protection, which uses the natural galvanic potential of different metals to protect a structure with a sacrificial anode. It's great for small structures like the hull of a ship or another accessible structure where the anode can be changed when it is depleted. However, this option is not so good for extensive buried infrastructure like pipelines or where an operator needs a constant and controllable current output.

The Total Life Cycle Cost of an ICCP system

When choosing the right solution for any particular site, it's important to evaluate the total lifetime cost of the different options to identify the least costly.

This should take into account the initial purchase price of the installation, operational and maintenance costs, as well as the salvage cost that can be obtained at the end of an installation's lifetime when components are sold for scrap.

Initial cost includes site surveys, engineering design and specification, delivery to site, installation and commissioning. Requirements are highly specific to the conditions for each installation. A typical ICCP system for a pipeline might draw 1 Amp at 5-10 Volts, whereas systems for well casings will draw 15-20 Amps at a similar voltage.

Specifications vary widely as the current drawn differs depending on the soil resistivity and moisture levels in the soil (or salinity of water for subsea installations), climate and the extent of the infrastructure to be protected.

During an installation's lifetime, operational costs include the cost of fuel or power from the grid, as well as the cost of visits by certified technician to inspect, test and deliver maintenance services. These can be costly for remote sites, which require long travelling time and coordination, to ensure that technicians have the right tools and spare parts with them to avoid the need for repeat visits.

When mains power is available, installations based on transformer rectifier units are typically the least costly – but this is not always possible, particularly for operators of oil and gas pipelines that run through uninhabited regions. It is just not practical or cost-effective to run a power line across a desert or a remote mountainous region.

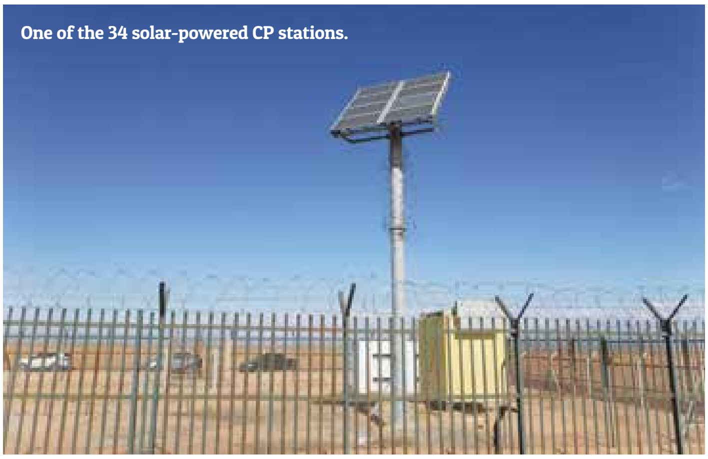
That leaves a comparison between systems based on diesel gensets and solar PV or wind power – and the high cost of fuel and logistics means that hybrid renewable power supplies are significantly more attractive as running costs mount up over a number of years.

An example of the use of a photovoltaic panel/battery system is given on the right.

Case study: Spie Oil & Gas Services

One operator that has adopted an ICCP system powered by solar PV and battery systems is the Hassi R'Mel gas field pipeline in Algeria. Located around 550 km south of Algiers in the Sahara Desert, the pipeline is 1,650-km long and stretches from the remote Hassi R'Mel gas field in Algeria to Qued Saf-Saf on the Tunisian border. The pipeline then feeds into Transmed's supply link that flows from Tunisia to Italy to provide Europe with gas. The field currently represents a quarter of Algeria's total gas output.

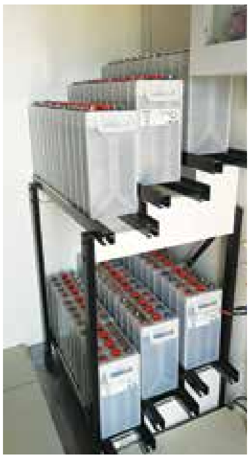
In 2018, Spie Oil & Gas Services installed an ICCP system that is powered by solar PV panels in conjunction with nickel-technology battery systems, to ensure a constant unbroken 100 Watt supply to keep the cathodic protection systems operating.


One of the 34 solar-powered CP stations.

The batteries were installed at 34 stations along the pipeline where they store energy from solar panels. During daylight hours, solar PV panels generate electricity to meet the demands of ICCP, run SCADA (Supervisory Control and Data Acquisition) systems and charge the batteries. When the sun sets and on overcast days, the batteries step in to maintain a continuous power supply. They are sized to provide up to five days of power to ensure the pipeline is protected even in rare extended periods of overcast weather.

Conclusion

There are some important considerations for engineers who specify batteries for remote sites, where a maintenance call-out can be costly and resource intensive.


A typical battery system for the Hassi R'Mel pipeline.

Batteries at such sites need to be tough enough to withstand the extreme heat and cold of the desert day and night and the mechanical stresses of transport to the site. Operators typically want to choose batteries that have a proven track record and have demonstrated high reliability in similar operating environments.

When choosing battery technology and sizing batteries, it's important to consider temperature, as it has a significant impact on battery performance and life expectancy. Nickel technology batteries are better able to withstand extreme high or low temperatures than lead-acid technology. Although lead-acid batteries have a low purchase price, they have a limited lifetime, which is further shortened in hot climates. A lead-acid battery system designed to provide five days of autonomy will last 10-11 years at 25C, or 5-6 years at 35C. In comparison, nickel battery technology will last up to 20 years, so is less costly over the lifetime of an installation. This has a significant impact on Life Cycle Cost of an installation therefore when selecting a battery system, it's important to use this as the deciding factor.

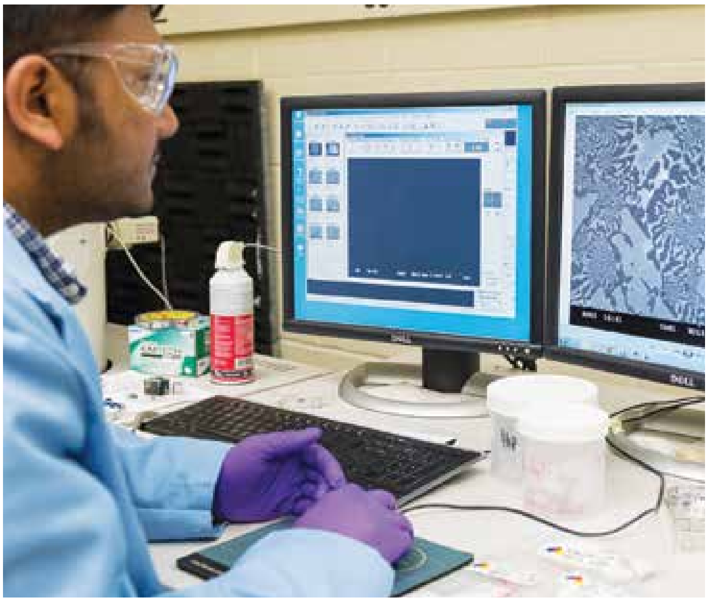
Typically for an ICCP installation, a battery will need to provide a minimum of 2 to 3 days of stand-alone power.

A new approach to evaluating corrosion in the oil and gas industry

Corrosion has long been recognized as a menace to energy and manufacturing industries, and fighting it can be a costly business. But it's a game that energy suppliers today are forced to play to reduce the risk of pipes bursting and the costly toll damaged pipes can inflict on human health and the wellbeing of the environment.

To combat corrosion, energy producers spend millions each year to coat and treat pipelines, and meticulously monitor and inspect thousands of miles of pipe. But technologies for monitoring corrosion are far from perfect, and the threat of corrosion persists. The oil spill caused by a burst pipeline on the coast of southern California, which happened less than five years ago, is among the latest examples. In parts of the broken pipeline, which left more than 100,000 gallons of crude oil along the coastline, 45% of the metal within the pipe wall had corroded away.

Research from the U.S. Department of Energy's Argonne National Laboratory offers a new, more thorough approach for understanding corrosion, and it comes from an unlikely source—the packages scientists build to secure nuclear waste for millions of years, known as waste forms. The new approach, developed by Argonne researchers Vineeth Kumar Gattu and William Ebert, holistically combines existing techniques for analysing corrosion rates to formulate more durable waste form alloys. Their approach has the potential to aid energy producers in evaluating and qualifying materials used in pipelines by using tools that are already at their fingertips



Vineeth Kumar Gattu reviews microscopy results of samples evaluated using Argonne's method. (Image by Argonne National Laboratory).

Similarities between material studies of nuclear waste forms and oil and gas pipelines

Like pipelines, nuclear waste forms are susceptible to corrosion over long periods of time. Aqueous corrosion, which occurs when the refined metals in pipes, bridges, cars, and other structures are contacted by water in the environment—such as rain or groundwater—is one common process leading to material degradation and failure. Another is microbial corrosion, which is promoted by the microorganisms within the soil..

Materials that are candidates for use as nuclear waste forms must withstand corrosive conditions deep underground when groundwater inevitably percolates through geological and engineered barriers and breaches waste containers. Similar expectations exist for oil and gas pipelines, but corrosive conditions can differ depending on the environment, in particular the accessibility of oxygen. Because pipelines are exposed to variety of external and internal environments, from seawater to farmlands, rivers, mountains, and urban landscapes, standards for materials will also vary.

Evaluating corrosion

Whether they happen in the soil or the sea, chemical and electrochemical reactions in solutions are the reason corrosion occurs. The corrosive stress of an environmental solution is defined by its chemistry. And in nature, the environment is continually changing. An important impact of the changing environmental conditions is a change in the solution redox potential and the voltage it imposes on the surface of the material—and, as Gattu points out, different environmental redox potentials can trigger different material responses. Some materials resist corrosion at higher voltages better than other materials.

As materials corrode in response to the environmental conditions, oxides are generated that can be non-protective, like rust, or protective, like chromium oxide, which forms on stainless steel. Over time, the layers and surface properties become stable and the rates of corrosion remain steady. But both the surface stability and corrosion rate can change when the environment changes.

Problems with existing studies

Aware of the critical impact environments can have on how materials corrode, Gattu and Ebert set out to find methods that could tell them how fast different materials corrode under the wide range of environmental conditions that could occur during the service life of a nuclear waste disposal facility. What they discovered is that standard tests fail to capture material responses over even a small range of environmental conditions.

Gattu and Ebert saw limitations in standardised electrochemical tests that are among today's most commonly used approaches for measuring how fast materials corrode. As Ebert and Gattu discovered, those tests measure a material's short-term response to its environment before the surface has stabilised under the environmental conditions. The tests indicate the propensity to stabilise, but do not measure the response of the stabilised surface.

"It's possible for materials to passivate, or form a stable barrier against corrosion, over time, but short-term tests can miss the effects of processes that stabilise the surface slowly," said Ebert, who manages the Pyroprocess and Waste Form Development group in Argonne's Chemical and Fuel Cycle Technologies division. "Short-term tests can also miss processes like leaching, which can end up destabilising the material's surface over time. Long-term corrosion can be slower or faster than the rates measured in short-term tests."

When using standard electrochemical tests, engineers rapidly scan a material over a standard range of potentials that could occur in an environment, Gattu said, but they only pick one condition to measure how fast the material corrodes.

"Most tests are conducted under one particular set of conditions, which may never occur in the actual service environment, but materials are qualified based on performance in that one standard test," Gattu said. "That's where I think there is a gap—material performance should be evaluated over the full range of conditions that may occur during service."

Without accounting for how material responses may change over longer periods, materials evaluated under only one set of conditions are at risk of failure under more aggressive conditions that may evolve over time but are not represented in qualification tests. By the same token, materials that are good candidates for specific applications may be ruled out prematurely if tests don't capture the effectiveness of a protective passivating barrier or surface layer that will form under the service conditions.

Implementing a more holistic approach

To improve existing methods and more accurately predict how a material will hold up in the real world, Gattu and Ebert developed a multi-technique approach to measure the corrosion rates under conditions likely to occur over the long term. Their approach combines a suite of electrochemical tests with microscopy and solution analyses.

Their electrochemical tests use an electrolyte to impose important chemical effects such as pH and chloride concentrations, and a potentiostat—a device that controls voltage—to fix the voltage of the material surface at values that could occur during service.

“The redox reactions occurring in the environmental solution generate an electrical potential on the surface and we’re representing those effects by using a potentiostat,” Gattu said.

Unlike in standard tests, Gattu and Ebert measured responses over long periods to allow surface layers to evolve and stabilise. They used electrochemical impedance spectroscopy (EIS), which is a technique for characterising the electrical properties of the oxide layers, to determine when the surface layer has stabilised and relate that to the measured corrosion rate. They considered the steady corrosion rate attained when the surface has stabilised to represent long-term behaviour and to quantify its effect on the corrosion rate at different potentials.

“That’s where the gap is. Standard tests, because they are so short, only capture the effects of surfaces while they’re still evolving. But these surfaces need to be given time to stabilise during the test as they will in nature,” Gattu said. “Through our method we can represent the long-term behavior that occurs after the surface has stabilized under the environmental conditions.”

Gattu and Ebert used their technique to study selected materials after identifying a short list of materials candidates using traditional screening methods. They ran tests on these materials under a wide range of chemical and surface potential conditions, measuring corrosion rates for each along the way. Those results led to improved formulations and more durable waste forms.

Understanding the physical nature of corrosion

While running tests with their approach, Gattu and Ebert collected additional data to help them understand in greater detail where and when corrosion is happening. They use microscopy to assess the surface of the material before and after the tests and analyse the solution to identify and quantify the materials that leached or dissolved.

Microscopic analyses were performed to identify different regions on the surface of the material that may corrode preferentially during the test. When combined, these approaches enable researchers to monitor when an oxide layer forms and when it finally stabilizes, measure the corrosion rate after a stable state has been achieved, and provide quantitative insights for predicting long-term behavior.

“Standard electrochemical tests run through so many different conditions so fast that we miss the particular condition when the material started corroding, what part of the surface is corroding, and, if there are multiple regions, which region corroded first,” Gattu said. “That’s where microscopy can help.”

Augmenting electrochemical tests with microscopy enables researchers to pinpoint the exact region(s) where corrosion is happening and differentiate localised rates of corrosion. Combining microscopic findings with the results of solution analysis also enables them to identify the elements that released into the environment and map them to specific phases or regions of their test material.

“A lot of people have done standard tests to measure the corrosion current for a particular environmental condition, but we use a holistic approach. We measure the solution. We measure the surface stability. We measure the corrosion rates for a wide range of environmental conditions so the story emerges when all these pieces are combined,” Gattu said.

Advantages and potential impact

Ebert and Gattu’s integrated approach has the potential to provide more accurate insight into how pipeline materials corrode over the long term, information that can help when it comes to formulating more durable materials and re-qualifying existing ones. The approach also has the potential to better evaluate the performance of coatings used on pipelines.

“We can apply our methods to coated materials, multiphase alloys and metal/ceramic composites, weldments, as well as many other materials to understand their corrosion mechanism, evaluate their performance, and predict their failure,” Gattu said.

A major advantage for industry is that the approach is easy to implement. It leverages tools with which most research laboratories are well equipped.

“That’s the best part—everybody already has the equipment. It’s just that everybody has been looking at these tests independently. We are combining a lot of analyses to develop an overall picture of material corrosion,” Gattu said.

Editors Note

The Argonne team is looking for collaborators. For more information, please contact partners@anl.gov.

DOE’s Office of Nuclear Energy funds Argonne’s research on nuclear waste forms. Application to non-nuclear materials was funded by Argonne’s Laboratory Directed Research and Development (LDRD) Program.