Cover Story

Control Corrosion From Plant Cradle to Grave

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Each segment of a process plant's life calls for its own corrosion-prevention strategy

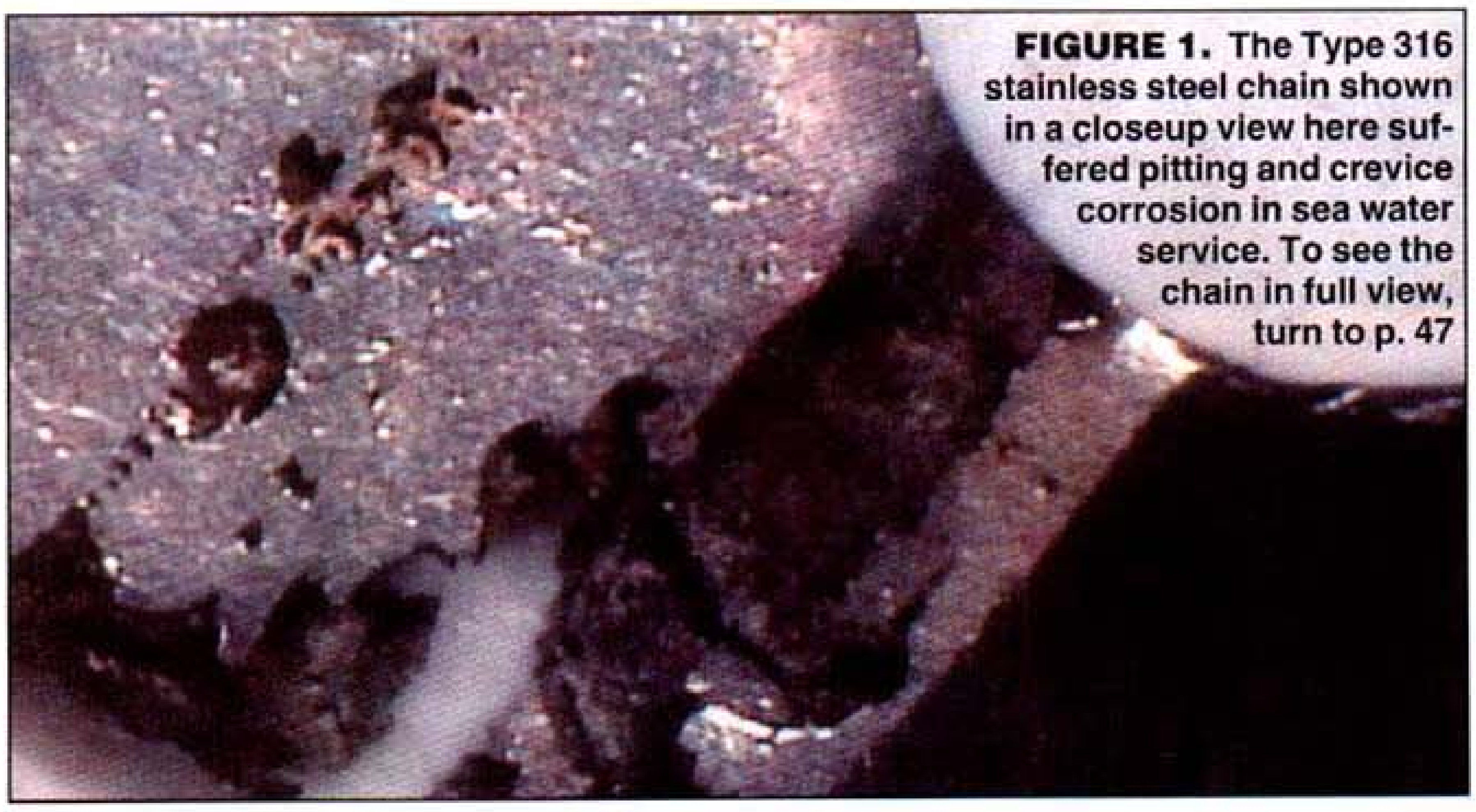


FIGURE 1. The Type 316 stainless steel chain shown in a closeup view here suffered pitting and crevice corrosion in sea water service. To see the chain in full view, turn to p. 47

To minimize corrosion problems, anticipate them and take proactive precautions in *all* phases of a plant's life: design, construction, operation and maintenance, and when the time comes for the plant to be mothballed.

During design, for instance, numerous materials selections may be feasible with different predicted corrosion rates. Choices made here affect the future inspection costs, maintenance frequency, operational flexibility and overall reliability. Also, corrosion control features can be incorporated during design for implementation during operation. Examples of these are velocity limits, inhibitor injections, and maintaining temperature limits.

All types of chemical-process plants, including less-obvious examples such as in biotechnology, can benefit from this cradle-to-grave attention to corrosion. In many process industries, such as those that employ acids or caustics, the potential for problems is well known. Less obvious is, for instance, the degree of corrosion challenge that water can present.

Corrosion is not only harmful in itself. Under some conditions, it can lead to operational problems, such as high pressure drop due to plugging by corrosion products, or accelerate metallurgical degradation. For example, corrosion can trigger or hasten erosion, or cracking due to metal fatigue.

PROCESS DESIGN – THE "CRADLE" PHASE

During the process design, the process chemistries and operating conditions are set by the chemical engineers, and process flow diagrams (PFDs) are created. Information from the PFDs is used to select the plant materials of construction, which are often documented on materials selection diagrams (MSDs). MSDs become the bases for filling in the materials-selection portions of the equipment data sheets, and they are key inputs for preparation of the piping and instrumentation diagrams (P&IDs).

Obviously, a key step in avoiding unacceptable corrosion is making a proper materials selection in the original plant design. MSDs facilitate the review of the materials' acceptability for the expected operating conditions, and the ensuring of consistency between adjacent piping and equipment.

All equipment components and subcomponents should be included. On shell-and-tube heat exchangers, for example, the materials for the shell, channel, tubes, tubesheet, floating head (if used) and baffles should all be specified. Vessel internals, valve trim and pump internals are examples of other subcomponents to be covered.

Ordinarily, the material, the corrosion allowance, the need for postweld heat treatment and the possible need for overlays or claddings should all be specified. And, be sure to make notations of any special requirements based on the service, such as velocity limits or inhibitor-injection needs.

Avoiding pitfalls

Painful experience has shown that the MSD should also provide information on some far-from obvious potential "traps." Two major examples follow.

The first concerns changes in pipe class. Often, bypasses around equipment connect two piping circuits that have different materials, such as Type 304L stainless steel (SS) and carbon steel (CS). If the bypass is expected to be used only intermittently, it should, as a minimum, use 304L SS up to and including the block valve. If the bypass is instead used frequently, the entire line may need to be of the 304L SS.

Another pitfall component that may need special review and added details is a drain line. For instance, in some SS piping systems, drain lines have been known to collect water when the unit is shut down for maintenance,

A CORROSION REFRESHER

Corrosion involves metal loss or penetration by a chemical reaction in which metal goes into solution or forms a scale which no longer provides the required strength and/or resistance to the service. Examples are the dissolution of carbon steels (CSs) in acids or the oxidation of alloys at high temperatures in air. Another form of corrosion involves cracking that penetrates through the metal wall as a result a reaction with the service. This phenomenon is called stress corrosion cracking (SCC). Some examples are carbon steels in alkaline services (under certain conditions) and brasses in ammonia especially with oxygen present. Corrosion mechanisms can be divided into aqueous corrosion and high temperature corrosion.

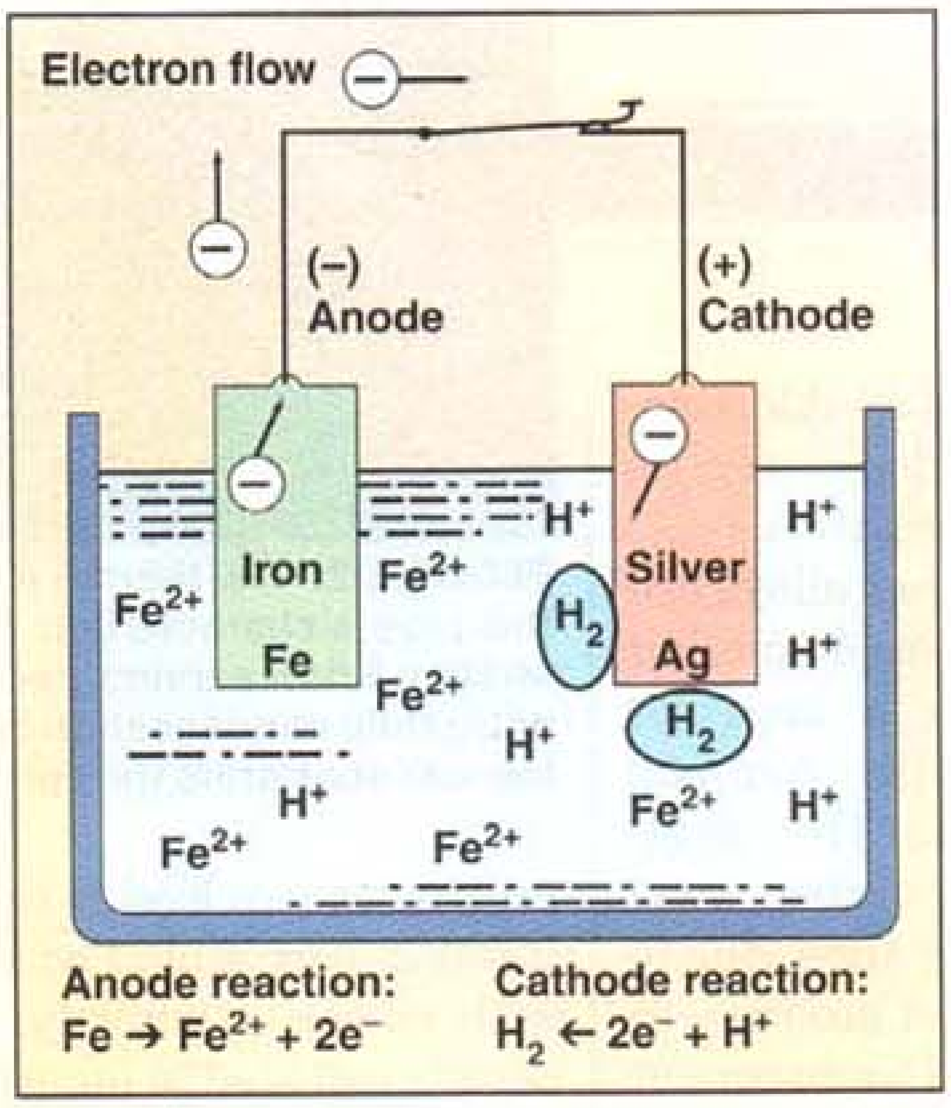
Aqueous corrosion

All aqueous-corrosion mechanisms involve the formation of an electrical circuit similar to a battery. This is why these mechanisms are also referred to as electrochemical corrosion. The four necessary components of these circuits are:

- Anodes: Locations at which corrosion occurs
- Cathodes: Surfaces that do not corrode; more "noble" than anodes. Protected from corrosion by coupling to anodes
- Electrical connections: Some forms of conductive connection between the anode and the cathode
- Electrolytes: Aqueous media in contact with both anode and cathode

The diagram shows a sketch of the current flow in these circuits. The anode and cathodes can be different areas on the same piece of metal. Typical electrolytes are sea water, oxygenated plant waters such as open tower recirculating cooling water, acids, water in soils, and other process waters containing chlorides.

Breaking the current flow in any way is a means of preventing corrosion. One example of stopping the current flow is by breaking the electrical connection by adding insulating flange kits to mating flanges of different metallurgies in services involving good electrolytes. Contact between the electrolyte and cathode can be prevented by applying organic coatings. Avoiding dissimilar metal combinations minimizes the "driving force" for corrosion, as does avoiding combinations of small anodes coupled to large cathodes based on surface area. The chemical reactions occurring at the cathodes and anodes are also shown in the figure.



The nine commonly defined types of aqueous corrosion are as follows:

General: Uniform thinning over the entire exposed surface. Some acids cause general corrosion. Some instances of atmospheric corrosion also falls into this category.

Atmospheric: External corrosion due to moisture, salts and pollutants in the air.

Pitting (can be underdeposit): Localized corrosion due to service contaminants which cause breakdowns in an alloy's passive film barrier, such as chloride pitting of Type 304L stainless steel (SS).

Crevice (can be underdeposit): Localized corrosion in tight gaps or shielded areas exposed to corrosive services. Examples are under bolts, rivet heads or gaskets, between lap joint surfaces or under surface deposits

Selective Dealloying: Attack of one element of an alloy. Dezincification, or the removal of zinc from brass, is a common example.

Galvanic: Corrosion due to the coupling of dissimilar metals within an electrolyte. An example would be the use of steel rivets to connect sheets of Ni-Cu alloy in seawater.

Intergranular: Localized corrosion at grain boundaries within the metal, while the grains remain relatively unattacked; results in grains "falling out."

Erosion Corrosion: Also known as velocity-sensitive corrosion. Involves accelerated corrosion due to removal of protective passive films by high-velocity or turbulent process streams. This corrosion is often limited to elbows, tees and similar areas. Sulfuric acid and naphthenic acid corrosion are velocity sensitive.

Stress Corrosion Cracking: Cracking caused by certain metal and service combinations, in the presence of a tensile stress. Examples are cracking of carbon steels in NaOH above certain concentrations and temperatures, or SS in hot chloride-containing waters.

High-temperature corrosion

In contrast to aqueous corrosion, some plants experience high-temperature-corrosion mechanisms. These mechanisms involve high temperature oxidation, sulfidation, HCl (which also causes aqueous corrosion), carburization/metal dusting, naphthenic acid corrosion, fuel ash corrosion and more.

The minimum temperatures at which these mechanisms become concerns varies by alloys and other factors. Roughly, HCl, sulfidation and naphthenic acid corrosion can occur on carbon steels at temperatures as low as 450–500°F (230–260°C), while the other mechanisms typically require greater than 900°F (480°C).

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and that water remains trapped until it boils away during startup. Chlorides in water have been known to induce stress corrosion cracking (SCC) of stainless steel drain lines. One way to avoid this potential problem is to specify that the drain lines be made of a higher alloy that is resistant to chloride SCC, such as Alloy 825 (38-46% Ni, 19.5-23.5%Cr, 2.5-3.5% Mo, 1.5-3.0% Cu and 22% min. Fe) [*1*].

Materials selection is usually based on the worst-case condition to arise during normal plant operation; for instance, at end of a plant run or in a fouled condition. Ordinarily, the materials selection need not instead be based on mechanical design conditions, the latter being based on mechanical-strength considerations in accordance with a design code, such as one from the American Soc. of Mechanical Engineers. But always be alert for the possibility of short-term process-related excursions, such as ones rapidly causing SCC, that could affect the integrity of the selected materials.

If the effects of excursions are more gradual or long-term, as is the case with sulfidation corrosion or many embrittlement mechanisms, or have an appreciable incubation time, such as hydrogen attack, then no measurable mechanical degradation is likely to arise , provided that the excursions are infrequent and short term.

Take the long view

In all materials selection, consider the long-range impact on equipment life and reliability, as well as on future maintenance, operation and inspection costs. On critical equipment, consider making a lifecycle cost analysis. A risk-based decisionmaking process can be used, taking into account such considerations as process severity (in terms of employee health-and-safety risks, temperatures, pressures, and similar factors), economic risks (considering the daily value of the operating unit, whether the equipment is spared, and so on) and inspectability. Obviously, the higher alloys should be chosen for critical equipment and piping, whereas easily replaceable components in nonhazardous service should use low-cost alternatives.

Keep in mind that higher alloys can sometimes be justified based on other considerations, such as a need for good heat transfer with minimal degradation over time. The heat-transfer coefficients for carbon steel tubes often decrease over time, due to the formation of corrosion products in the form of scale and subsequent buildup of deposits that become attached to the scale. Stainless steel may provide a payout with better and more-consistent heat transfer. This is the case for power-plant surface condensers, and for many vacuum distillation tower overhead condensers.

During the design stage, it is often beneficial to have materials specialists audit data sheets, P&IDs and equipment drawings, to ensure that all materials and special requirements were properly "picked up" from the MSDs. Furthermore, the P&IDs and equipment drawings have many more design details than those addressed by the MSDs, and the materials specialist can provide fresh input on items that might influence future corrosion or other degradation mechanisms.

PROCUREMENT, CONSTRUCTION – BUILD IT RIGHT

The choice of welding and fabrication techniques can affect corrosion for years to come. Improper welding procedures, postweld heat treatment, bending and bolting are among the factors that can all lead to future corrosion or cracking.

Keep in mind that some alloys, such as duplex stainless steels, require the welding heat input to be within a certain range if the corrosion resistance of the weld is to be as good as that of the base metal. Some alloys require the weld metal to be overalloyed with greater-than-usual amounts of alloying metal (such as nickel), in order to offer equivalent corrosion resistance. Some services, such as sulfuric acid, require gas-tungsten arc welding (GTAW) for the root pass. This requirement is to ensure a smooth weld bead on the inner surface, as excessive protrusion can lead to turbulence that initiates corrosion. Poor-quality welds with excessive porosity, slag or other defects can lead to increased corrosion in many aqueous services.

FIGURE 2. The thinner wall at the top of this pipe is characteristic of pipes in stratified-flow service, because vapor and acidic condensation contacting the top can accelerate the corrosion there

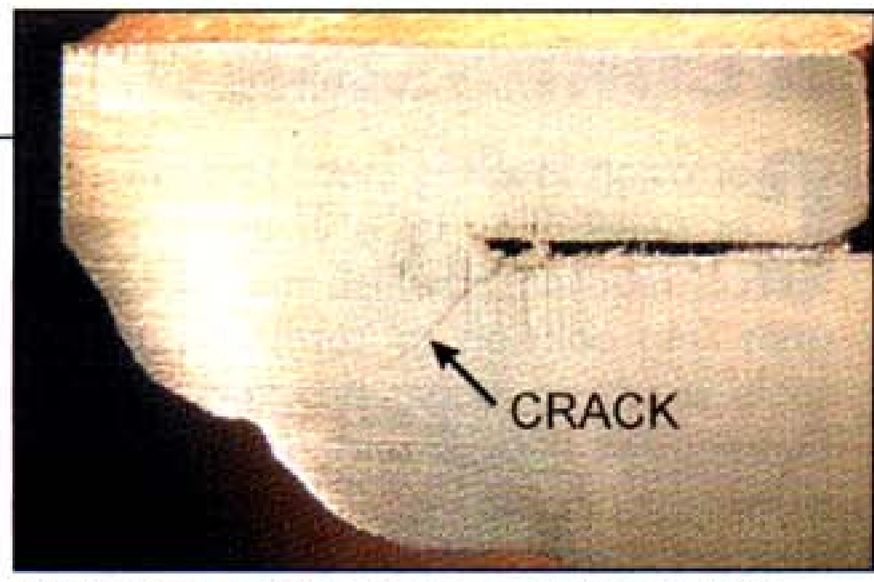

FIGURE 3. This piping socket weld in steam service suffered caustic stress corrosion cracking, emanating from the root of the weld. The steam was "contaminated" by severe carryover of boiler feedwater

Issues like these are generally addressed via notes on the MSD or within the various project pipeline classes, other specifications or the equipment data sheets. Such attention to detail is especially important for those services that require postweld heat treatment (PWHT) to avoid stress corrosion cracking. The PWHT should be specified on the MSD and then on the applicable line classes and equipment data sheets.

Emphasize the importance of avoiding either further welding or heat-based straightening upon vessels or piping which have received PWHT. This warning is often painted on the outside of the vessels and piping. Even small external welds can lead to the start of stress corrosion cracking on the inner surface.

Proper application of protective internal coatings or linings (where specified) is also an important step of the construction phase. Examples include the use of epoxy linings in water tanks, and of rubber linings in slurry-handling equipment. Proper application generally calls for specialists in that task. Of course, external painting is also a key factor in avoiding external corrosion.

Today, almost all new-construction projects implement a Positive Materials Identification (PMI) program. This program involves verifying that a component or weld is the correct metallic material, with the aid of a nondestructive analyzer. The petroleum-refining industry has recently issued a recommended practice entitled API RP 578, "Materials Verification Program for New and Existing Alloy Piping Systems," May 1999.

Most plant owners require that the final PMI be made after the piping or vessel fabrication. Admittedly, to avoid later rework, most fabricators will PMI the bulk components (such as pipes, elbows, tees and flanges) as-received, and use stamping or paint striping to ensure the correct components are used for each spool (each section of pipe along with its valves, fittings and other accessories). But errors still occur, and the final PMI testing after fabrication is clearly justified. Projects are still showing significant reject rates, which indicates that these programs are still needed.

Water quality for hydrotesting is an important consideration when the material of construction is stainless steel. Many specifications limit the water to 50 ppm chlorides maximum, or allow higher chlorides for testing if a final rinse with lower-chloride water is used. After hydrotesting, it is important to quickly drain and dry the tested equipment, especially for stainless steel. Trapped water can lead to chloride pitting, or microbiological corrosion that can cause significant pitting in just weeks.

After the plant construction is complete, and before the startup, a cleaning phase is required for removing debris and contaminants. This phase can be as simple as a rapid flush for a water line, or, at the other extreme, a scrupulous cleaning and de-oiling for an oxygen line. For typical process plants, however, the cleaning phase will include the following sequence of steps:

- De-oil or alkaline boilout: This step removes oils (drawing oils, protective films, grease, pipe thread oil, and so on) left behind by fabrication, and prepares the surfaces for acid cleaning,
- Acid cleaning: In most cases, the interior surface of new equipment contains rust and mill scale, which must be removed to prevent further corrosion and as well as possible operational problems. The acid cleaning is completed by neutralization

SUMMARY OF SOME COMMONLY-USED NDE TECHNIQUES TO MONITOR CORROSION

NDE technique	Description	General corrosion; thickness remaining	Localized corrosion, pitting	SCC on accessible surface	SCC on inaccessible surface		When used	
					Detection	Sizing	On-the-run*	During shutdowns
Visual (VT)	Includes examination with unaided eye, magnifying glasses, mirrors, borescopes, etc. Requires good surface cleanliness. Limited to surface corrosion or defects.	C	A	C			Ext. only	X
Dye penetrant (PT)	A penetrant is applied to the surface, which enters cracks and defects by capillary action; the surface is then cleaned and dried; developer is applied and the penetrant bleeds out to indicate defects. Limited to tight, surface-breaking defects. Some penetrants contain fluorescent dyes, and are viewed under black lights.			A				X
Magnetic particle (MT)	A magnetic field is established in the test areas with prods or yokes; and magnetic particles such as iron filings are applied. The particles accumulate at cracks or defects, which cause disruptions in the magnetic field and an accumulation of the particles. Can only be used on magnetic materials. Wet and dry methods; also, fluorescent particles are available, which are viewed under black lights.			A				X
Straight-beam ultrasonics (UT)	A ultrasonic beam is transmitted straight into the material and the time for the back reflection can be converted to wall thickness. This technique also detects laminations or other midwall defects oriented parallel to the surface.	A	C				X	X
Shear wave ultrasonics (UT)	A ultrasonic beam is transmitted into the material at a specific angle; if it hits a crack, some of the wave is reflected back. By motion of the transducer back and forth, the depth of the crack can be roughly determined. Requires a skilled operator.				A	B	Occ.	X
Contact radiography (RT)	A radiograph with no cross-sectional view, but used to detect pitting or cracking in an area (thinner areas show up darker). No precise corrosion-depth measurements can be obtained, but the relative depths can be estimated by the differences in color.		B		C		X	X
Profile radiography (RT)	A radiograph with a cross-sectional view. With a penetrameter or other item of known thickness placed in the radiograph to determine the magnification ratio, the wall thicknesses at each point in the cross-section can be determined.		A		C	C	X	X

A = Commonly used to detect this type of corrosion; a reliable detector
B = Can be used to detect this type of corrosion under certain conditions or with some limitations
C = Occasionally used to detect this type of corrosion, but with significant limitations
SCC = stress corrosion cracking

* Most methods have a maximum temperature limit for use during plant operation.

and rinsing, as well as passivation

- Passivation: Following acid cleaning, a passivation step is normally performed to prevent rapid (flash) rusting. Typical passivating agents for carbon steel include inorganic phosphates or nitrites. A handy reminder goes as follows: positive passivation prevents pathetic performance.

PLANT OPERATIONS: NOTE THE IMPACTS OF CHANGES

As we have seen above, plants are designed and built containing corrosion provisions that are based on specific expectations as to how the plant is to operate. So, the obvious ways that corrosion problems can arise during plant operation are:

- If the operating conditions basically change, or
- If temporary excursions occur that which exceed the original expected conditions (which had been used for the materials selection) by enough of a margin that the materials are no longer resistant.

Temperature excursions as small as 10 Fahrenheit degrees can be significant for some mechanisms. Numerous other operating changes can induce corrosion, among them ones involving feedstock properties, velocities, the product specification, waste recycle and energy conservation.

Two protective strategies

MOC processes: One strategy that some plants employ to avoid these problems is to adopt a management-of-change (MOC) processes. In the U.S., in fact, the Occupational Safety and Health Administration requires a formal MOC procedure for certain types of plants, among them petroleum refineries. In an MOC process, any proposed operating changes are reviewed, primarily for safety and for process, environmental, and mechanical acceptability. The acceptability criterion can, of course, take into account the amount of impact (such as increased corrosiveness) that the proposed changes will have on the existing materials.

On MOC forms pertaining to changes that could affect corrosion, either the plant's materials specialist should be listed as an approver, or the materials specialists and inspectors should receive copies.

Operating envelopes: A different strategy to cope with the corrosion implications of plant-operations changes consists of setting "operating envelopes" beforehand. The process conditions are reviewed for each piece of pipe and equipment, and the potential corrosion and other degradation mechanisms pertaining to it are defined;

then, the process-change limits to avoid degradation are determined. For example, a maximum temperature to avoid hydrogen attack, based on the hydrogen partial pressure or the minimum sulfuric acid concentration in a recirculating stream, may be set.

These limits are then compared to the limits set for process optimization. If the corrosion-prevention limits are tighter, they may become the new control-room alarm limits. If the corrosion-prevention limits are instead looser, they are nevertheless kept on file, and are used in reviewing future proposed changes.

Aside from being of cautionary help concerning proposed deliberate process changes, process envelopes are also useful with respect to unplanned short-term excursions. When an excursion arises, process envelopes help determine whether immediate protective actions or inspections are needed or if, instead, the excursion is too brief to affect the equipment.

Corrosion-control procedures

During plant operation, the operating procedure should include certain tasks for corrosion control. Examples include injection of corrosion inhibitors (such as filming or neutralizing amines), cleaning, cathodic protection, and passivation.

Inhibitors: Neutralizing amines are commonly used where acidic condensation can occur. Other inhibitors might be necessary to minimize, for instance, corrosion due to hot potassium carbonate (used for carbon dioxide removal from gas streams).

Inhibitors are, thus, not general-purpose reagents. Take care in selecting them to achieve the desired results, and establish the best location for inhibitor injection, the appropriate injection hardware (such as quills or spray nozzles) and the most suitable diluent for the inhibitor. Poorly designed systems have led to severe corrosion at the injection points.

Most inhibitor-injection setups include a corrosion probe. Monitoring of the injection activity not only can spot incipient corrosion but is also a key to maintaining cost effectiveness.

Cleaning: Proper cleaning, either online or between batches, is also important for resisting corrosion with many processes.

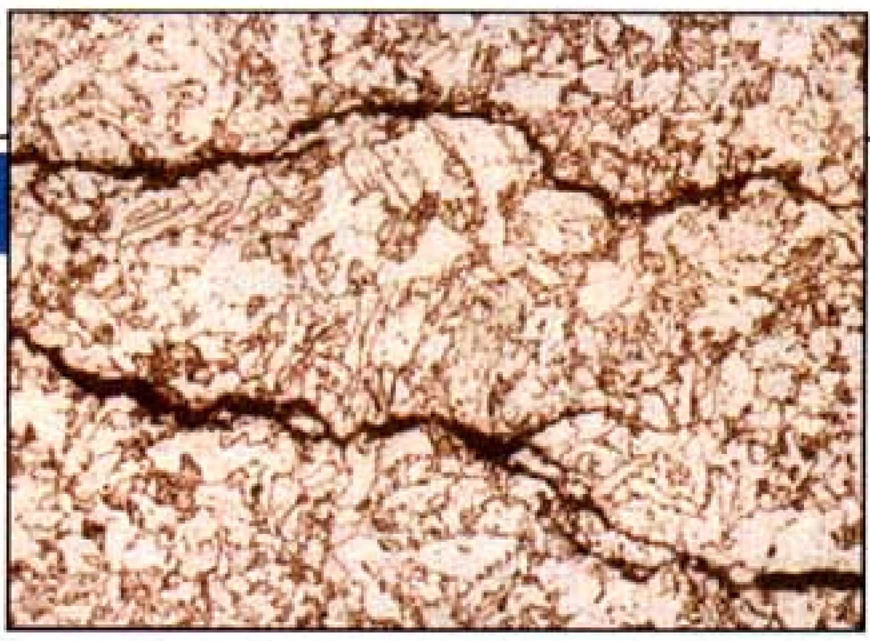

FIGURE 4. The caustic stress corrosion cracking shown in Figure 3, p. 44, exhibits this classic branched appearance at higher (100X) magnification

In many industries, online acid cleaning is periodically needed to remove salt deposits from heat-exchanger or other surfaces. To avoid corrosion, the acid cleaning should be kept to short exposures, and inhibitors should be included in the acid solutions. If acid cleaning is being done on a water-cooling exchanger as part of a cooling-tower system, the exchanger effluent should be sent to the effluent treatment system during the cleaning (and the cooling tower blowdown should be reduced by a corresponding rate), to avoid sending the water laden with acid and deposits back to the cooling tower. Other techniques are used to remove microbiological fouling.

In the biochemical industry, cleaning is done mainly to prevent contamination. But in some biochemical processes, cleaning is also necessary to maintain the proper passivation layers on the metal and to avoid rouging (*CE*, August 2001, pp. 101–104).

Cathodic protection: Cathodic protection (CP) is a form of corrosion protection that uses the principles of electrochemical corrosion to protect metal. The component to be protected is made into a cathode by attaching it to anodes of less noble metals (such as zinc, magnesium or aluminum) or to anodes through which a current is supplied from a rectifier. The former approach is called sacrificial-anode CP; the latter, impressed-current CP.

CP is commonly applied externally to buried items, such as underground process pipelines and water- or gas-distribution lines, and to tank bottoms that are in contact with soils, to protect them from wet soil corrosion. It is also employed with most subsea items, such as pipelines and offshore platforms. However, internal CP is also used, and its most common application is in water tanks and vessels. When CP is a key part of the corrosion protection, monitoring and periodic adjustments are required.

Passivation: Protection of a cooling-water system against corrosion is greatly enhanced by a prepassivation of the system before original start up, as well as passivation after cleaning or other maintenance. The water-treatment-chemical vendor can help determine the optimal passivation method and recommend solutions. But, in general, prepassivations with an open tower, recirculating system can be done by any of three ways:

- Adding concentrated dosages of chemicals to the cooling tower basin, and circulating the resulting solution through the entire system after all heat-exchanger bundles are installed but while they are still cold. After the circulation, blowdown before startup must be thorough, to avoid excessive fouling
- Dipping individual bundles in the concentrated passivation solution
- Circulating the solution through individual bundles before installation, with the aid of a skid-mounted tank, pump, and heater.

INSPECTION, MONITORING – FIND PROBLEMS EARLY

Many process units are designed with some acceptable corrosion rate and, consequently, operating lifetime in mind, while also relying on nondestructive examination (NDE) to monitor the metal loss and define the optimal time for equipment replacement. The actually experienced equipment lives often prove to be longer than the original predictions, which necessarily stem from conservative assumptions. Inspection is also critical to find any unpredicted corrosion, or higher-than-predicted rates. The typical NDE methods appear in the table on p. 45.

Selecting the proper inspection locations within the plant, and having a reasonable number of inspection points, are important components of the inspection program. Guidance for petroleum refiners is given in various industry standards, such as API 510 for vessels, API 570 for piping and API 653 for tanks. In addition, proper recordkeeping is needed to ensure that the same spots are inspected after the next time interval (often years later) and that the readings are tracked to indicate corrosion rates.

Using inspection methods that are

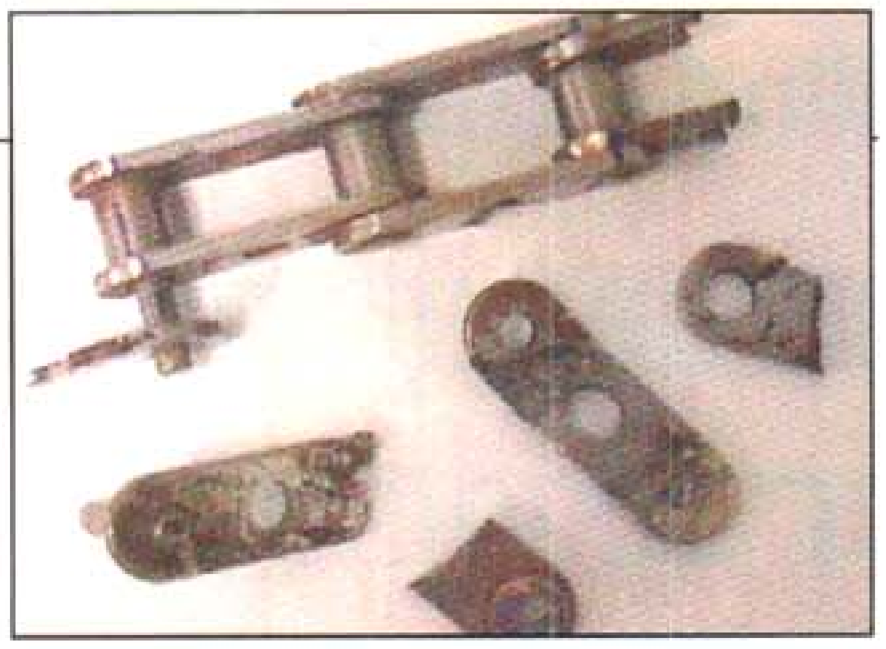

FIGURE 5. In this stainless steel chain in seawater service, rapid crevice corrosion began where the chain links contacted the pins that join the links, then progressed to the outer surface. The chain broke after merely months of service

appropriate for the expected degradation mechanisms is also important. For some lines or equipment, multiple methods should be used. For example, thickness measurements via straight-beam ultrasonic testing (UT) are appropriate for to pick up general thinning in the equipment — but if pitting is occurring, it is often missed by straight-beam UT programs because only a small percentage of the surface area is measured, and because this type of UT cannot obtain readings in areas where the inner surface is rough. Hence, automated UT, internal visual inspection (perhaps with borescopes) or profile radiography with multiple shots may be needed.

New, arrayed UT probes and other techniques are also being developed to help detect and size pitting. Cracking, such as SCC or hydrogen attack, also require more-specialized techniques. Newer UT shearwave techniques are being used to locate and size many of the SCC mechanisms.

Risk-based inspection (RBI) is a relatively new trend that is being used to ensure that the inspection is focused on the highest priority items. Programs employing RBI first evaluate the potential damage mechanisms in a given piece of equipment or piping, then determine their likelihood to cause problems (also considering the detectibility by inspection), and finally evaluate the consequences of those problems (including safety risks, replacement costs and time, potential operational losses, and other criteria). For a given case, the RBI rating is the quantified likelihood multiplied by the quantified consequence.

Among the relevant petroleum-refining industry documents are: API RP 580, "Risk-Based Inspection" and Publication 581, "Base Resource Document – Risk-Based Inspection." These documents were issued in May 2002 and May 2000. The first-named defines three levels of analysis: Level 1 is primarily qualitative, Level 2 is partly quantitative and partly qualitative and Level 3 is highly quantitative. In all programs, a critical first step is an accurate determination of the predicted damage mechanisms. This determination typically requires extensive involvement of a materials engineer working with the other plant specialists, including the operators, process engineers and inspectors.

Other monitoring is done by using corrosion probes, hydrogen probes, permanently attached UT transducers, or similar probes. Two commonly-used types of corrosion probes are:

- Linear polarization resistance probes (LPR), for aqueous streams which have high conductivity and are not prone to heavy fouling, such as oxygenated fresh cooling water. These probes give readings of instantaneous corrosion rates in mils or millimeters per year.
- Electric resistance probes (ER probes), to monitor both aqueous and high-temperature general corrosion mechanisms. They have limited applicability for pitting or localized corrosion. The readings are indicative of average metal loss, and corrosion rates can be found by plotting readings over time

Hydrogen probes measure the amount of hydrogen generated by corrosion. They can be used to indicate corrosion severity, but are more commonly employed to provide an early warning of potential hydrogen-cracking conditions. Often this cracking is caused by changes in process conditions that result in a sudden increase in the amount of hydrogen generated by relatively-minor corrosion.

Some process monitoring is also being done to indicate the onset of potential corrosion problems. Typical examples are monitoring of:

- Process variables with strong effects on certain solution corrosivities, such as pH and sulfuric acid concentration,
- Elements that greatly increase in concentration directly as a result of corrosion, such as iron from corrosion of steels, or copper or nickel from their respective metals, or
- Residues of inhibitors or other chemicals that are added for corrosion control.

MAINTENANCE: PROACTIVELY PLAN FOR REPLACEMENTS, REPAIRS

All aspects of maintenance — preventative, proactive and reactive — include some activities that are made necessary by corrosion, and/or can affect future corrosion control.

For instance, preventative on-line maintenance may involve periodic cleaning of pH probes that are used to avoid corrosion, or of instrumentation plugged with corrosion products that are migrating to the area from metal loss occurring upstream.

An example of proactive maintenance is replacement of a heat-exchanger tube bundle in cooling-water service with in-kind materials as it nears the end of its operating life, as predicted from periodic inspections. Months prior to a major shutdown, the inspection and maintenance records of all equipment and piping should be reviewed to determine which items are due for replacement.

So long as an acceptable, economic operating life was achieved, in-kind replacement is justified. Many reviews have shown that lives on carbon steel heat-exchanger tubes would need to be less than five years in order for upgrading alloys be economically attractive, but this guideline is subject to many application-specific details. If time to the first scheduled turnaround is longer or if a high degree of reliability is needed, the higher alloys may become preferable.

Cleaning to allow equipment and piping to be opened for maintenance must follow procedures in order to avoid corrosion. For examples, lines or equipment containing sulfuric acid or elemental sulfur need to be cleaned quickly and thoroughly to avoid pockets of corrosive material left at low points. Even a few days of exposure to dilute sulfuric acid, especially in the presence of air, can cause significant metal loss. After cleaning or hydrotesting, it is important to quickly drain and dry equipment, especially when fabricated from stainless steel. Trapped water can lead to chloride pitting, or to microbiological corrosion that, in turn, can cause significant pitting in just weeks.

Maintenance often entails welding. As during the construction phase, postweld heat treatment is in many cases essential for avoiding cracking and corrosion during the future operation. Maintenance welding is often done in-place, with poor access, dirtier conditions, or other factors making it more difficult to work to the same quality as obtained in shop fabrication. Accordingly, the quality control needs to be especially diligent.

As for reactive maintenance, many instances of unpredicted corrosion or cracking are found during shutdown or turnaround maintenance. Or, a leak due to corrosion may be the cause of an unscheduled shutdown. In such cases of reactive maintenance, it is important to make a root-cause investigation. This investigation typically includes identifying the damage mechanism, determining a corrective action to prevent it from happening again, and recommending the inspection of any additional plant areas in which the same mechanism could also be occurring.

MOTHBALLING OR STANDBY: A NEW SET OF CORROSION CONCERNS

When a process unit is taken out of service, cleaned, dried and then left unused for some time period for potential restart in the future, protection from corrosion remains a requirement. There are good references on mothballing which contain extensive checklists and options [*2*].

External corrosion during standby can become significant on a cold unit, especially if the insulation gets wet. Insulation is often removed for long-term mothballing. As for protection against internal corrosion, among the aids are desiccants, volatile corrosion inhibitors and spray-on oil coatings.

A process unit is often on standby between batches, or to handle seasonal variations in product demand. Often such units must be able to start up quickly, so they are sometimes completely sealed and under some pressure. For example, nitrogen blanketing or the recirculation of a noncorrosive, noncontaminating fluid may be used. In some cases, certain equipment is kept hot, or under operation, by recirculating a solution and maintaining some heating. One example consists of lightly firing a furnace.

Whatever the standby conditions are, the existing plant materials of construction should be reviewed for acceptability. Some instances may call for special corrosion-prevention steps (such as adding inhibitors) or additional monitoring.

FINAL THOUGHTS

Corrosion is a factor in all phases of a plant's life, and has obvious impacts on the safety, reliability and profitability. These plant phases include design, procurement, construction, operation, maintenance, inspection, standby operation and mothballing. Knowledge of the potential damage mechanisms is critical to setting the correct preventative actions and maintaining plant integrity throughout each phase. Keep in mind that the actions regarding corrosion in any one phase can significantly affect the costs in another.

The biggest benefit of corrosion prevention is the avoiding of leaks, fires and unplanned shutdowns, with the resulting safety risks, environmental hazards, equipment damage and lost production. Those are the primary areas where proper materials selection and corrosion control can affect a plant's bottom-line profitability. ■

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References

1. Shargay, Cathleen, and Messer, Barry, Some Current Issues and Cost Saving Ideas for SS Use on Refinery New Construction Projects, *Stainless Steel World*, pp. 28–35, April 2002.
2. Twigg, Ronald J., "Guidelines for the Mothballing of Process Plants," MTI Publication No. 34, Materials Technology Institute of the Chemical Process Industries, Inc., St. Louis, Mo., 1998.

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