Avoiding corrosion in process piping

Piping materials, fabrication methods, process stream changes all need review.

Whenever a change in the process operation or stream makeup is contemplated, an evaluation should be made of the effects of the change on plant equipment. To prevent corrosion, it may then be necessary to make changes in the materials or the process system, add or change inhibitors, or perhaps consider other changes in the stream itself that will not lead to corrosion of the system components.

Some time ago, a brand new stainless steel pipeline in a cosmetics plant began to leak before it had been placed into operation. Investigation showed that a hypochlorite sanitizing solution had been left in the pipe too long and had caused serious pitting corrosion.

In another plant, a seemingly insignificant change in the process stream caused extensive corrosion in the process equipment.

Such stories indicate that corrosion in process piping can be serious. They also illustrate that causes and the onset of corrosion are not always recognized and sometimes nothing is done to prevent it until a failure occurs. Corrosion can be controlled, however, and by recognizing the factors that cause it, the plant engineer can prevent expensive failures, losses of production, and even injuries.

Design

Corrosion often can be controlled by using the appropriate design. Many design parameters affect corrosion, including crevices, fluid velocity, material selection, use of protective coatings or other protective measures, use of different metals together, temperature, pressure, internal and applied stresses, and process chemistry (including the presence of contaminants).

One example of improper design contributing to corrosion failure involved flue gas scrubber piping. The piping consisted of Schedule 10 AISI 316L stainless steel with welded fittings. The piping was used to handle water from a coal-fired furnace flue gas scrubber system. This pipe was in service for less than a year when leaks developed. The flue gas scrubber water had the following chemistry: 2 to 2.6 pH, 145 to 260 ppm chlorides, 2,200 ppm suspended solids, 250 ppm dissolved solids, and 2,300 micromhos-cm conductivity.

The investigation revealed that the leaks were caused by corrosion pitting. The pitting was caused by active-passive corrosion cells initiated beneath sludge deposits. Fluid velocity in the larger pipe runs was calculated to be approximately 1.2 fps; a minimum fluid velocity of 5 fps is usually recommended. Sufficient velocity prevents deposits from settling and permits the protective oxide film on the stainless steel to be maintained. The low velocity in this example allowed sludge to deposit on the pipe. Had the...
pipes have been designed with a sufficient velocity, then failure might have been averted.

It is, of course, not always possible to design with the proper parameters for a given material. For the scrubber piping, a flow of 5 fps was not practical. In that case, a corrosion-resistant material, fiberglass-reinforced plastic (FRP), was the best selection. However, if other conditions, such as temperature or pressure, are too high for FRP, then a more corrosion-resistant metallic material is needed. Carbon steel pipe with a lining, such as PVC, polyvinylidene fluoride, or a fluoropolymer, is also an alternative for the example cited.

Not all corrosion protection systems work in all cases. An example of a corrosion protection system inappropriately applied concerns a pasteurizing tank in the food processing industry. The tank was constructed of mild steel to which a metallized zinc coating was applied. Hot water of varying temperatures is sprayed on the product as part of the pasteurizing process. Severe corrosion of the steel occurred despite the sacrificial zinc coating.

**Shortly after the plant changed from a once-through to a recycled process water system, water tests showed a tenfold increase in electrical conductivity.**

The investigation revealed that the zinc had developed a passive layer in the particular water used and not only did not protect the steel but actually increased corrosion of the mild steel. Sacrificial zinc anodes placed in the tank became passivated themselves and did not protect the steel. The solution was to use either a sacrificial cathode that did not passivate in that water, a high performance barrier coating, or both. The use of sacrificial anodes should be carefully evaluated to ensure that they will perform as intended.

**Fabrication**

Fabrication techniques and processes, including cut treatment, welding procedures, machining and cutting methods, can affect corrosion. An example involves the use of AISI 304 stainless steel pipe used to handle syrup in a food processing industry. The pipe developed Tests the heat affected zone (HAZ) of welds. A metallographic examination revealed chromium carbide precipitation in the HAZ. This condition, known as grain boundary sensitization, renders the stainless steel more susceptible to corrosion grain boundaries, and this caused the leaks.

Extra low carbon grades ("L" grades) of stainless steel are usually used to prevent chromium carbide precipitation where welding is to be done. An alternative is to use stabilized grades, such as AISI 347 or 321.

Another example of failure caused by fabrication procedures involved AISI 304 stainless steel used to handle deionized water. This pipe failed even before it was placed in service; the leaks developed during a disinfection procedure.

The failure investigation revealed a small degree of grain boundary carbide precipitation near welds. Pits were also found at random locations elsewhere on the pipe. The disinfection procedure called for a hypochlorite solution to be circulated through the pipe for a few hours. The hypochlorite solution was allowed to stand in the pipe for up to 48 hours, a period several times in excess of the plant standard procedure. Laboratory tests proved that pitting could be initiated in this pipe material within 24 hours.

The obvious lesson here is to be sure that fabrication procedures are not destructive to the materials of construction. In this example, the piping was so badly damaged that it had to be replaced and the proper disinfection procedure used. An alternative, milder disinfection procedure involves the use of ozone.

Quality of fabrication can affect the performance of the material. The flue gas scrubber pipe in the example cited previously also suffered from leaking at field welds. A metallographic examination revealed that the welds contained porosity and roughness. The rough condition allowed additional deposits to form, and the porosity served as built-in initiation points for pitting and crevice corrosion.

**Process stream changes**

What has been said about the best laid plans of mice and men can apply to process piping too. Changes in plant operation, modifications to the product, or changes in the process stream may create corrosion problems where none existed before. A plant designed to withstand one process stream may suffer damage if the stream is changed or its operation altered. Whenever changes are contemplated, an evaluation should be made to see what the impact of the change will be on the piping and other components involved.

**Modifying the product**

A food processing plant utilized a syrup in the manufacture of a cereal product. The syrup was carried in a 304 stainless steel pipeline that had been functioning well for several years. Then the syrup was changed by increasing its salt and water content. Shortly thereafter, corrosion failures began to occur in the pipeline. Plant management was naturally concerned. Investigation revealed crevice corrosion at flanged joints and also intergranular corrosion at some welds due to carbide precipitation at grain boundaries. The increase in the salt and water content of the syrup had initiated corrosion.

This seemingly insignificant change in the syrup composition caused severe headaches for plant management. The problem revolved around the fact that stainless steel derives its corrosion resistance from a surface oxide layer. This layer must be maintained through contact with oxygen or some oxidizing agent. A breakdown of the oxide layer leads to corrosion, usually in the form of pitting.

Crevice corrosion occurs because of reduced oxygen content within the crevice. Chlorides, which also tend to break down the protective oxide layer on the surface of stainless steel, play an important role in crevice corrosion.
Chlorides migrate into crevices and form metal chlorides that then hydrolyze to form hydrochloric acid. The acid lowers the pH and increases the rate of corrosion.

The corrosion at welds stemmed from a fabrication problem but did not show up until the syrup formulation changed. Type 304 stainless steel is susceptible to sensitization, i.e., the formation of chromium carbides at grain boundaries from welding or heat treatment. The carbides make the grain boundaries less resistant to corrosion and also create galvanic cells between the grain boundaries and the base metal of the pipe.

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The best solution to this problem is removing the salt from the water or at least returning the salt content to its original concentration. Switching to a corrosion-resistant pipe is also an alternative. Teflon-lined pipe or highly alloyed steel are alternative materials.

**Debris in the process stream**

Changes made in the product manufactured may affect process water and cause corrosion. Such a change occurred in a glass fiber insulation manufacturing plant. About two years before failures began to occur, a change was made to a finer fiber with a different binder. Erosion and corrosion, as well as pitting failures, were found in conveyor line wash-water piping and in sheet metal air cleaning enclosures.

The wash-water system, utilizing a flow rate of 3,000 gpm, functioned to clean the exhaust air from the plant and to clean the conveyor used to form the insulation. Waste was filtered and dewatered, and the water from the dewatering process was returned to the process system. The water itself was not naturally scale-forming, so it tended to be corrosive. In addition, in the process system the water picked up chloride and sulfate ions, adding to its corrosiveness. During the air cleaning operation, the water picked up large quantities of oxygen. All of these factors combined to make the water corrosive to the metal piping and other components of the system. By itself, the water may not have caused significant corrosion due to the protective corrosion product films that formed on the metal surfaces. The fibers in the water abraded the protective films, however, and exposed bare metal to the corrosive water. This led to the erosion and corrosion failures discussed earlier.

Filters had been installed in the original system. With the change to a finer fiber, however, the filters were able to remove only about one-third of the glass fiber debris from the washwater. New filters needed to be installed to remove as much particulate matter as possible. In some cases, larger diameter pipe was required to reduce velocity and decrease the erosion and corrosion that still might occur even with the better filtering.

Here again is a failure that could have been prevented had proper consideration been given to the effects of a change to a finer fiber. It should have been apparent that a change in filtering might have been needed to screen out debris. A discussion of monitoring follows, and here is a case where monitoring of the process stream would have revealed an increase in the fiber content of the water. If plant engineering personnel had been aware of the danger of erosion and corrosion caused by this increase in fiber content of the process water, action could have been taken to prevent the damage that occurred.

**Monitoring and maintenance**

We have presented some examples of failures that occurred because processes were changed without concern for the corrosive effects of the change. This does not always happen, however. Frequently, plant engineers evaluate the effects of change and make preparations for it. Process operation changes A good example of evaluating a change took place in a paper products plant. For many years, the plant had utilized a once-through white water system. Water was obtained from a river and returned to it after passing through the plant. Environmental concerns brought about regulations that prohibited the discharge of the spent water into the river. As a result, the plant changed from a once-through system to a recycled system.

After the recycled system had been in operation for some time, the plant operators became concerned over the possible corrosive effects the recycling operation might have on process piping and forming rolls. The change had a major impact on the throughput of water. In the once-through operation, about 25 million gallons of water per day flowed through the system. Under the recycling operation, only about 4 million gallons per day of fresh water were added.

The once-through system had permitted the fresh incoming water to mix with the constituents of the stream and carry away unused solubles, suspended solids and/or debris. There was no buildup of dissolved substances in the water. This helped keep the corrosiveness of the liquid low. Often, such once-through systems are even less corrosive than recycled systems that use inhibitors.

Tests on the process water showed a tenfold increase in electrical conductivity (from 50 to 500 micromho-cm). This increase was brought about by the retention of salts in the stream, thus increasing the total dissolved solids content of the water. The increased conductivity (decreased resistivity) led to a proportional increase in the rate of corrosion of both bimetallic couples and of the steel itself. That corrosion was indeed occurring was confirmed by the presence of 2.0 to 3.8 mg per liter of iron in the process water, as compared with 0.27 mg per liter in the raw supply water.

Another result of the change to the recycled system was a reduction in pH from approximately 6.2 in the raw water to approximately 4.0 in the recycled stream. The lowered pH tends to dissolve protective films on aluminum components of the process equipment and thus
The diligence on the part of the plant operators in recognizing the possibility of corrosion enabled them to take steps to control corrosion before serious damage occurred. The first step was to monitor parameters of the process stream to determine the general operating conditions. Once these were known, steps such as changes in piping materials, use of inhibitors, and elimination of bimetallic junctions were taken.

**Process stream changes**

Occasionally a change is contemplated in the process stream itself. Once again, it is important to assess the impact these changes will have on corrosion. An example of this took place in a kaolin (water and clay) slurry operation. The process engineers had contemplated the addition of sodium hypochlorite to the slurry. Of particular concern was the effect this would have on 316 stainless steel, 6061-T6 aluminum, and carbon steel components of the piping and process equipment.

A laboratory study was conducted using the proposed kaolin slurry to evaluate the corrosive effects on the components of the process stream. The study also evaluated the usefulness of several coatings for use on process equipment. It was found that the addition of sodium hypochlorite to the slurry would not increase the rate of general corrosion but would be conducive to pitting corrosion and especially to crevice corrosion of the aluminum components. No problems with stress corrosion cracking or intergranular corrosion of stainless steel were indicated, however. It was also found that the existing slurry was corrosive where deposits accumulated.

As a result of the study, it was determined that the proposed kaolin slurry could not be used without taking measures to control corrosion. It was recommended that pipe joints and fittings be disassembled to determine if there were places where slurry deposits might collect. Avoiding slurry deposits would minimize the possibility of crevice and other corrosion attacks. It was also found that polypropylene or PVC-lined steel pipe should be used in place of the unlined steel pipe with which the system had been constructed.

**Corrosion monitoring**

Regular monitoring of corrosion in process equipment will help prevent failures and unscheduled maintenance. Monitoring of the process stream will disclose changes that might increase or decrease the corrosiveness of the stream. Steps can then be taken to effect protective measures or return the stream to its normal condition. Monitoring is also necessary to evaluate the effectiveness of corrosion control.

Monitoring can be accomplished in various ways. Whenever components of the process system are disassembled, the parts exposed to the stream should be examined. Any pitting or other deterioration should be investigated and corrective action taken.

Ultrasonic thickness measurements of piping, vessels and other components of the process equipment can be made during plant inspections. Such measurements will indicate whether thinning of the metal is occurring, although it may be difficult to detect pitting corrosion by this method. If corrosion is detected, steps can be taken to arrest it before failures occur.

Many process plants utilize corrosion coupons, consisting of small samples of the various metals found in the process system. The samples are mounted on special holders and exposed to the stream. At regular intervals, the coupons are removed, examined and weighed. Rates of corrosion can be calculated from the weight loss of the coupons. Once again, corrosion control measures can be initiated or adjusted to minimize corrosion.

Corrosion rate probes can also be inserted into the stream at strategic points. The probes measure the rate of corrosion either by changes in the electrical resistance of the probe due to loss of metal or by electrochemical polarization methods. Probes can provide continuous monitoring of corrosion, and prompt action can be taken to correct problems when they are discovered.

Monitoring the makeup of the process stream will yield data that may signal an increase or decrease in the stream's corrosivity. Changes in the composition or velocity of the stream should be evaluated to determine if the changes will cause corrosion damage.

**Conclusion**

Whenever a change in the process operation or stream makeup is contemplated, an evaluation should be made of the effects of the change on plant equipment.

As with all other aspects of plant operation, the preventive maintenance program needs to include corrosion control. If it does, plant safety will be enhanced and failures and plant downtime will be minimized. A proper corrosion control program helps keep a plant running at peak efficiency and reduces costs from corrosion failures, unscheduled maintenance and loss of production.

John H. Fitzgerald III is Vice President of PSG Corrosion Engineering Inc., a consulting engineering firm headquartered in Detroit.

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Before joining PSG he worked for Columbia Gas of Ohio. He has been involved in corrosion work for more than 30 years, and teaches short courses on a regular basis. Mr. Fitzgerald, who graduated from the Yale University School of Engineering, is the author of about 40 technical papers. He is the recent past president of the National Association of Corrosion Engineers.

Walter T. Young works for PSG Corrosion Engineering Inc. from his base in West Chester, Pa. A graduate of Drexel University with a B.S. degree in metallurgical engineering, he has extensive experience in the design of cathodic protection systems and corrosion surveys for industry and utilities. Mr. Young has been involved in corrosion work for various manufacturing plants and also for the U.S. Navy, the Federal Highway Administration, the U.S. Forest Service and the Port Authority of New York.

More information on this subject is available on request.

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