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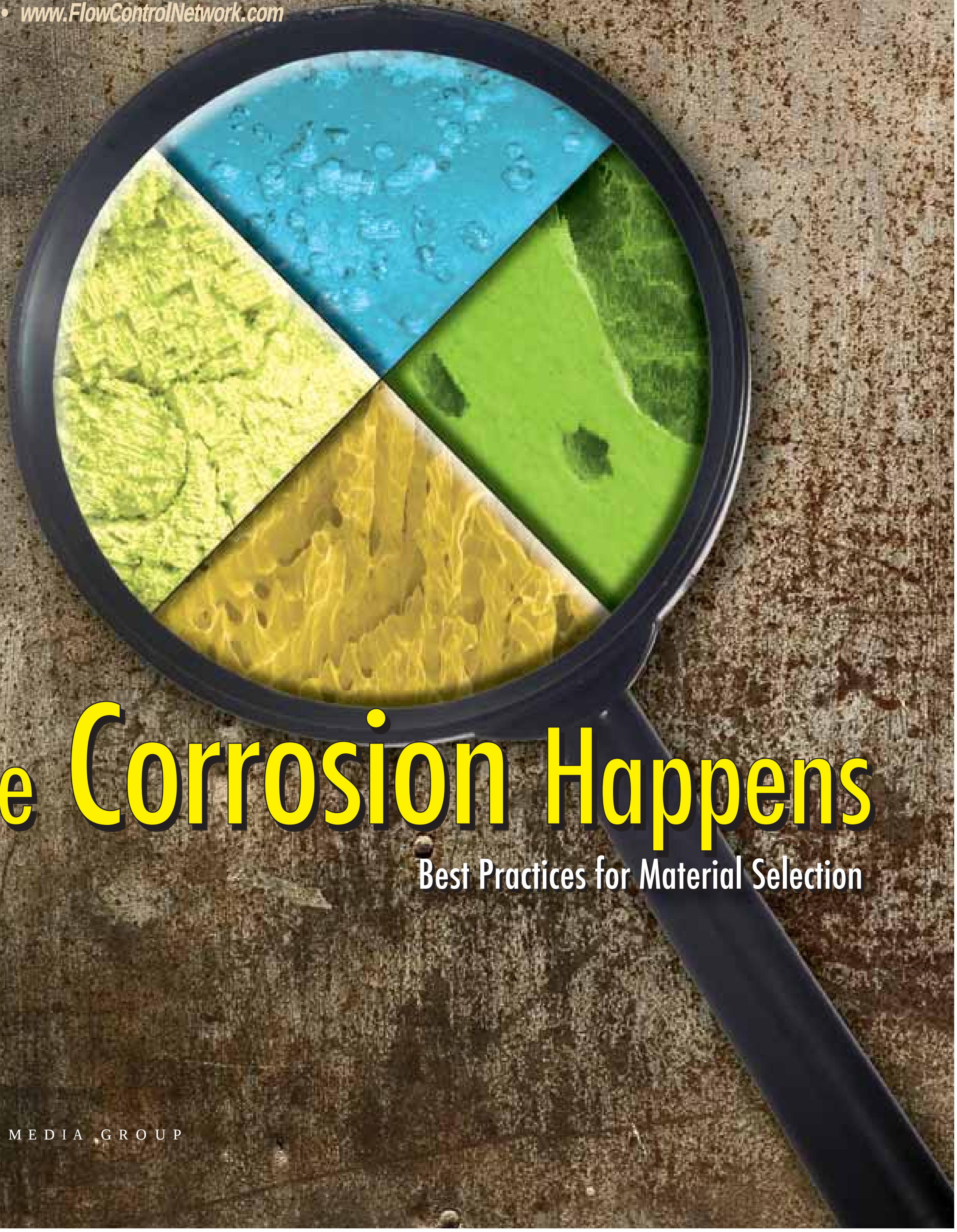

Because Corrosion Happens

Best Practices for Material Selection

GRAND VIEW MEDIA GROUP

by Gerry Berry

Strategies for Proper Material Selection

Lessons Learned from 30 Years of Application Experience

Proper selection of materials of construction is an important factor to ensure overall fluid handling systems reliability. The *Micro Motion Corrosion Guide* from Emerson Process Management (*www.emersonprocess.com*) is the product of 30 years of application experience and represents a one-of-a-kind reference for proper material selection. The following gleans some information from this guide to provide users some best practices for selecting materials that will increase service life for devices in a processing facility.

Considering the Problem

Corrosion is the degradation of a metal or alloy caused by its reaction with an environment. Metals and alloys rely on the formation of an oxide layer for protection. The integrity of the oxide layer is dependent upon both the metal and the environment. For reliable protection, the oxide layer must be uniform. For example, iron will form an oxide layer, but this layer is not necessarily uniform or protective against corrosion. On the other hand, by adding 12 percent or more of chromium to the iron (as is the case with stainless steel), a tenacious and uniform oxide layer is formed. This layer provides protection for a large portion of the corrosive environments commonly found in industry.

One alloy or metal will not serve all environments, and the compatibilities are complex and often counterintuitive. For example, tantalum is highly resistant to acids, such as hydrochloric, yet poorly resistant to caustics. High concentrations of caustics are compatible with expensive nickel-chromium-molybdenum (Ni-Cr-Mo) alloys, yet the same alloys are not compatible with nitric acid, which works best with the least expensive alloy, 304L (without molybdenum).

Characterizing Corrosion Resistance

Emerson uses several tools to inspect incoming materials while also testing components and joining operations at each stage of the manufacturing process. To more fully understand the effects of corrosion in a range of applications, inspections are also performed on devices that are returned from the field. Tools for inspection include X-ray equipment, PMI (positive material identification), scanning electron microscopes with energy dispersive X-ray, ultrasonic thickness measurement devices, Hall-Effect gauges, potentiostats to characterize corrosion rates and behavior, and hardness and microhardness testers.

Emerson recently released in-situ verification technology for its Micro Motion Coriolis meters, which is particularly good news for processes that are prone to corrosion. The new technology detects changes to the mechanical integrity of the flow tubes along with evaluation of electronics. Early stages of uniform corrosion are characterized by loss of the flow tube material, which means the tubes become thinner and lighter. The meter verification routine can detect a change before it significantly affects the meter's ability to measure mass flow and before there is a breach in the tube.

Material Compatibility

To make reliable predictions about the compatibility between a given chemical and material of construction, several fundamental questions must first be answered:

- What corrosive agents are in the process and in what concentration range?
- What is the process temperature range?
- What material is being used for the piping?
- What cleaning cycles exist, and what fluids are used in these cycles?
- What is the velocity (particularly important when handling sulfuric acid)?

With answers to these questions it is possible to make a prediction of process compatibility.

The *Micro Motion Corrosion Guide* is essentially a repository of test data that has been accumulating over decades of testing and field experience with customers on hundreds of thousands of applications. It also takes advantage of the collaborative knowledge of the global National Association of Corrosion Engineers (NACE, *www.nace.org*), where ideas and experience is shared. As such, it includes virtually all typical chemical applications and many extraordinary and unique ones as well. For the most part, anything missing from the guide is merely something that either has never been tried or has never caused a problem.

A table for sulfuric acid compatibility, excerpted from the *Micro Motion Corrosion Guide*, is provided on page 22 with cutouts of the relevant legends.

Additional Considerations

Even after identifying the primary corrosion factors, there are still other considerations to be made before the compatibility between materials and process streams can be reliably predicted for a given application.

- **Erosion:** If the process contains solids moving through the pipe at high speeds, mechanical erosion of the materials could occur. The particles can be in a liquid slurry or even a gaseous stream. In corrosive environments, the solids might also scour the protective oxide layers, causing erosion-corrosion. An example of erosion-corrosion without particles is sulfuric acid. In sulfuric acid, there is a threshold surface velocity at which the sulfuric acid removes the protective oxide layer. Below the threshold, corrosion rates are negligible; above the threshold, corrosion rates increase significantly in a nonlinear trend.

- **Ambient Environment:** The ambient environment, on the other hand, has little effect on internal tubing corrosion. However, envi-

Fluid Name	Temp. (˚C) Low	Temp. (˚C) High	Conc. (%wt) Low	Conc. (%wt) High	Material Compatibility SS	HY	TZ	TA	TI	Notes
Sulfuric Acid[1]	-18	24	65	75	X	X	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	-18	24	75	98	C	O	O	O	X	Maintain Velocity < 5 ft/sec
Sulfuric Acid[1]	24	38	0	10	O	O	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	24	38	10	40	X	O	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	24	38	40	75	X	X	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	24	38	75	85	-	-	O	O	X	Maintain Velocity < 4 ft/sec
Sulfuric Acid[1]	24	38	85	93	-	O	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	24	38	93	98	O	O	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	38	52	0	5	O	O	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	38	52	5	25	X	O	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	38	52	25	75	X	X	O	O	X	Maintian Velocity < 10 ft/sec
Sulfuric Acid[1]	38	52	75	90	-	-	O	O	X	Maintain Velocity < 3 ft/sec
Sulfuric Acid[1]	38	52	90	98	-	O	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	52	54	0	5	X	O	O	O	X	Maintain Velocity < 10 ft/sec
Sulfuric Acid[1]	52	54	5	75	X	X	O	O	X	Maintain Velocity < 10 ft/sec

SS = Stainless steel
HY = Hastelloy C-22
TZ = Tefzel-Lined 316L
TA = Tantalum
TI = Titanium

X The selected material is not compatiable with the environment
O The selected material is compatiable with the environment
- No data available
C Conflicting data

** Excerpted from the Micro Motion Corrosion Guide*

ronmental conditions, such as high humidity or coastal environments, can cause corrosion of any exposed electronics, which makes it important to ensure all electronics are protected.

- **Cleaning:** It is easy to overlook the effect that cleaning practices may have on materials. A clean-in-place/sterilize-in-place (CIP/SIP) process is performed at high temperatures with cleaning agents (such as dilute NaOH) that are harmful to some metals and alloys. When these procedures are performed quickly, corrosion is negligible. However, CIP/SIP processes are often performed before a shutdown, such as overnight or before a weekend. If the piping is not designed to drain completely, cleaning liquids can puddle, giving them hours, or even days, to corrode the materials.

Process Challenges

Occasionally, process engineers and operators experience unexpected variation of concentration and contaminants in their process and/or waste streams. In some cases, these unknowns cause corrosion.

Environments with halogens (i.e., chlorine and fluorine) are the most insidious. In this case, the corrosion is localized, not uniform.

Figure 1a. *This cross-section through a Ni-Cr-Mo alloy (UNS 06022) tube after exposure to a high concentration of hydrochloric acid resulted in large pits (2X).*

In Coriolis flowmeters, for example, aqueous solutions with concentrations below 100 PPM are compatible with stainless steel at ambient temperature. At elevated temperatures, the allowable levels of halogens decrease for vibrating stainless steel tubes.

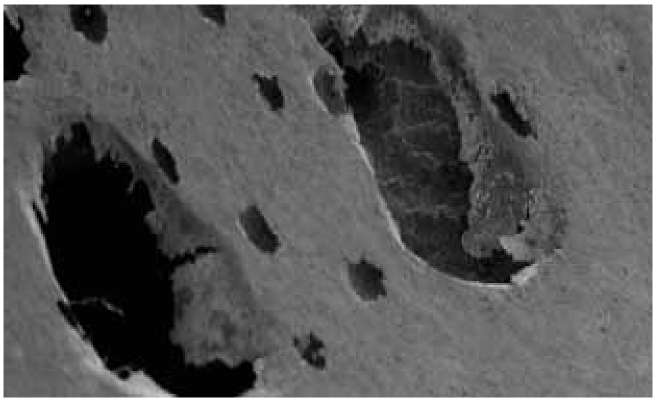

Figure 1b. *This SEM image at 20X reveals the localized attack of the hydrochloric acid. For high concentrations of hydrochloric acid, tantalum is compatible.*

The chloride attack on the oxide layer is localized and forms pits. Once a pit forms, the environment inside the pit becomes more aggressive than the process stream, hence the crack growth rate increases (Figures 1a & 1b). For Coriolis meters, the crack also creates a stress riser that is detrimental to the vibrating tubes. Consequently, preventing the formation of pits is paramount. Concentrations above 100 PPM need to be served by the Ni-Cr-Mo alloys or tantalum. The presence of hydrogen sulfide in gas, sour crude oil, and waste streams is another common cause of unexpected corrosion.

Another particularly difficult situation is when systems are subjected to a mixture of chemicals or large temperature swings. Some processes will mix hydrochloric with nitric acids. Low concentrations of hydrochloric are compatible with Ni-Cr-Mo alloys, yet nitric will attack the molybdenum (Figures 2a & 2b).

Finally, minor changes in the process can result in severe corrosion. For example, anhydrous hydrofluoric acid is compatible with stainless steel provided moisture is absent. However, severe corrosion occurs if any moisture becomes present.

Metallurgists, chemists, and other scientists continue to make and report progress in understanding, predicting, and ultimately preventing corrosion of process control and measurement devices. By thoroughly understanding the dynamics of materials of construction and effects of a wide range of process fluids, it is possible to make processing facilities more efficient, more productive, and safer by preventing unexpected failures caused by corrosion. FC

Figure 2a. *This cross-section through a Ni-Cr-Mo casting (CW-2M) after exposure to nitric acid reveals the dendritic microstructure (1X).*

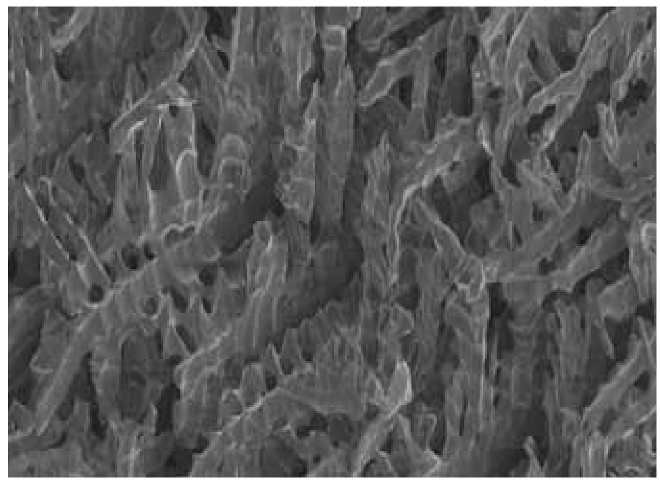

Figure 2b. *This SEM image at 80X reveals the dendritic structure within one of the colonies. The molybdenum-rich regions have been preferentially corroded away deep inside the casting. For nitric acid, CF-3 (304L cast equivalent) without the molybdenum is compatible.*

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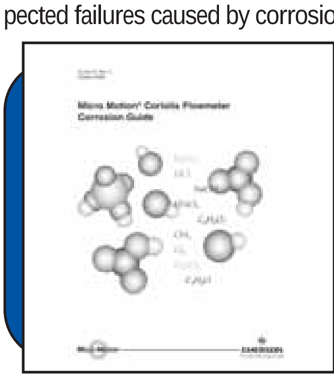

The Corrosion Guide: A Tool to Help Prevent Corrosion

Emerson's *Micro Motion Corrosion Guide*, now in its seventh revision, offers a repository of corrosion testing results and field experience. It can be downloaded on the Micro Motion Web site, under "Documentation" (*www.micromotion.com/documentation*).

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