Coatings versus Anodes

"Where Engineering Meets Ingenuity"

INTRODUCTION

Corrosion of surface facilities reportedly costs the oil industry over $589 million dollars annually. In an effort to slow it down we apply corrosion protective coatings, and/or chemical corrosion inhibitors. Sometimes we even install anodes. This paper makes an effort to offer a practical explanation of why the cures to corrosion we use either work or don't, and why it often makes sense to combine cathodic protection with coatings, and may not always make sense to use chemical corrosion inhibitors.

CORROSION

Corrosion is defined as "The breaking down or destruction of a material, especially a metal, through simple chemical reactions. Corrosion occurs when elemental iron leaves a steel structure and goes into solution into water. Water is the carrier that must be present for corrosion to occur.

The most common form of corrosion is oxidation or rusting, which occurs when iron combines with oxygen and water. In the oil industry the oxygen often originates in the form of carbon dioxide (CO_2) which reacts with the iron in steel to form iron oxide and/or ferric chloride in the presence of salt water. Another common cause is the presence of hydrogen sulfide (H_2S) which creates a chemical reaction that exchanges elemental iron from the surface of steel structures or pipelines (Fe^{++} or Fe^{+++}) with molecular hydrogen (H_2) to form iron sulfide.

Corrosion occurs at the molecular level in what we call "corrosion cells". Corrosion cells are similar to the cells of a battery, when electrical current flows from the positive portion (the anode) to the negative portion (the cathode). Such cells can exist on any metal surface. Like a battery, current flow in corrosion cells depends on the electrical differential within the cell and that differential can be measured. We find that the maximum electrical potential in a corrosion cell is just less than -850 millivolts (-850 mv).

COATINGS

Since corrosion cannon occur where there is no water, and because most oilfields produced fluid streams contain large quantities of water, one method of corrosion mitigation is the application of protective coatings. Any coating that isolates the metal from the water will stop corrosion.

Early efforts to coat steel with simple coating like tar showed promising results for a time, but as the tar coatings broke down and disbonded from the surface of the steel corrosion was found to be even more aggressive!

Over time we learned that coatings applied over a dirty surface tended to disbond rapidly, whereas coating applied over a clean surface would stay adhered longer. We also found that coatings had more tenacity and longer life when applied over a rough clean surface as compared to a dirty and/or smooth surface. Sand and metal blasting became metal preparation standards.

As the coatings industry became more sophisticated simple coatings like tar gave way to more reactive coatings; often two component epoxies. These exothermic coatings formed a tighter bond to properly prepared metal surfaces, extending their lives.

However, as more and more development occurred in coatings chemistry and surface preparation, it became obvious that achieving a 100% coating efficiency was unrealistic. Additionally, it was found that the corrosion rate of an entire uncoated structure would concentrate in the tiniest flaw in a coating, accelerating the metal loss into that tiny area. This meant that the general corrosion that might occur over the entire surface of an uncoated steel structure would now occur in a tiny area resulting in the very rapid penetration of the steel structure from this concentrated corrosion.

> *EXAMPLE: A 4' x 10' FWKO with a 3/8" shell has about 125 square feet of shell area. Uncoated, it is likely that the shell would corrode rather uniformly, losing perhaps 1/100th of its wall thickness annually. That's equivalent to a uniform metal loss of 0.00375" per year. This is roughly equivalent to a metal loss of only 0.45#/year. Assuming uniform corrosion, shell would completely dissolve in 100 years, a corrosion rate we would consider quite acceptable. However, if the vessel were internally coated and a single flaw the size of a pin head existed in the water phase of the vessel, a 0.1 amp corrosion reaction concentrated in this very small area could chew through the 3/8" shell in just 100 days (14.2 weeks)!*

The key practical points here are:

1. *There is no such thing as a perfect coating. All applied coatings have small flaws.*
2. *Vessel shell failure may be far more rapid in the coating flaw areas (aka "holidays") of coated vessels than in uncoated vessels.*

If we stopped here it would be easy to conclude that coatings are not effective. But in fact, they are often quite effective. The reasons are many and perhaps the key reasons are:

1. *All corrosion cells become rapidly coated with hydrogen bubbles as the hydrogen in water exchanges with the iron leaving the steel. Here's how … and why it's not the ultimate solution:*
    a. *Water (H_2O) is really made up of equal numbers of hydrogen (H^+) ions and hydroxyl (OH^-). The free hydrogen radical (1/2 $H_2 = H^+$) is quite unstable and immediately combines with its twin to for, a molecule of hydrogen gas (H_2).*
    b. *As corrosion takes place the iron (Fe^{++} or Fe^{+++}) goes into solution in the water, reducing the mass of the steel it came from. As this occurs the steel becomes immediately deficient in the positive electrons the iron took with it. This makes the corrosion cell highly attractive to other positively charged ions or molecules, and in water there is no greater concentration of anything positive than hydrogen (H^+).*
    c. *Since hydrogen is the smallest element in the universe, and a hydrogen gas molecule is also the smallest molecule, hydrogen gas bubbles migrate rapidly into the corrosion cell. Again, these are the smallest molecules there are, so when they cover the corrosion cell completely the cell is no longer exposed to water (the electrolyte in this micro-battery), and corrosion stops. You can see this if you tie a galvanized nail onto a piece of string and dip it into a glass of pool (muriatic) acid. The zinc coating on the nail will effervesce violently for a few seconds, and then stop. Once the reaction stops you can see that the nail is covered with bubbles … bubbles of hydrogen gas. This is "Mother Natures" perfect coating.*
    d. *However, hydrogen gas is extremely fragile, and quite volatile. Any movement in or around the corrosion cell and th3e hydrogen will be dispersed, and corrosion will begin again. In the case of the nail in the acid (in "C", above), once the bubble formation stops the corrosion, a tug on the string releases the hydrogen, and the bubbling corrosion reaction starts all over again! In the real world the any movement is enough to keep the hydrogen flushed out of the corrosion cells, and to keep corrosion going strong. Fluid flow does this. So, natural corrosion inhibition only occurs in the most quiescent of places, like the corners of tanks where the shell meet the bottom in oilfield tanks, or sometimes in holidays of internal coatings.*

Furthermore, coatings degrade over time. Most coatings need to be inspected for deterioration every few years, and repaired to keep them functioning properly. It is generally understood that the typical oilfield costing may need to be replaced every 5-7 years.

So, coatings help slow down corrosion, but if we stop there, corrosion is really a crap shoot and has unpredictable outcomes. Since corrosion from coating failures can be unbelievable costly in terms of oil spills from leaks and resulting fires, equipment failures, and downtime costs, many facility engineers agree that if there is a way assure the success of coatings so we know that we can and really do stop corrosion, we should take that approach.

One sure way to assure complete corrosion mitigation is the proper application of cathodic protection … or in simplest of terms, the installation of anodes!

ANODES (CATHODIC PROTECTION)

Corrosion is a science. It can be measured, quantified, and it can be controlled.

The science of corrosion control via cathodic protection uses the reality of the current flow in the typical corrosion cell against itself. Cathodic protection is the science of creating an artificial corrosion reaction that overwhelms the normal corrosion cell. This sounds difficult, but it is not! It's relatively easy!

If we stop the positively charged iron from leaving the steel structure, we stop corrosion. To stop galvanic corrosion we simply need to create a battery that reverses the electron flow of the corrosion cell. To accomplish this we select a metal structure that we're willing to sacrifice (the anode) to our artificial corrosion cell. This can be a chunk of a metal like zinc or an alloy of zinc, aluminum, etc. that has an electrical potential difference with steel, so that when the two are connected electrically, and both exposed to water, the anode corrodes and the structure we want to protect (the cathode) stops corroding.

This works as long as the electrical differential between the two has more than an 850 mv differential compared to steel. By selecting sacrificial anodes made from materials that have this potential difference the anode sacrifices itself at a rate that exceeds the -850 mv natural corrosion cell driving force in the corrosion cells on the structure we are trying to protect, stopping corrosion in its tracks.

IMPRESSED CURRENT CATHODIC PROTECTION

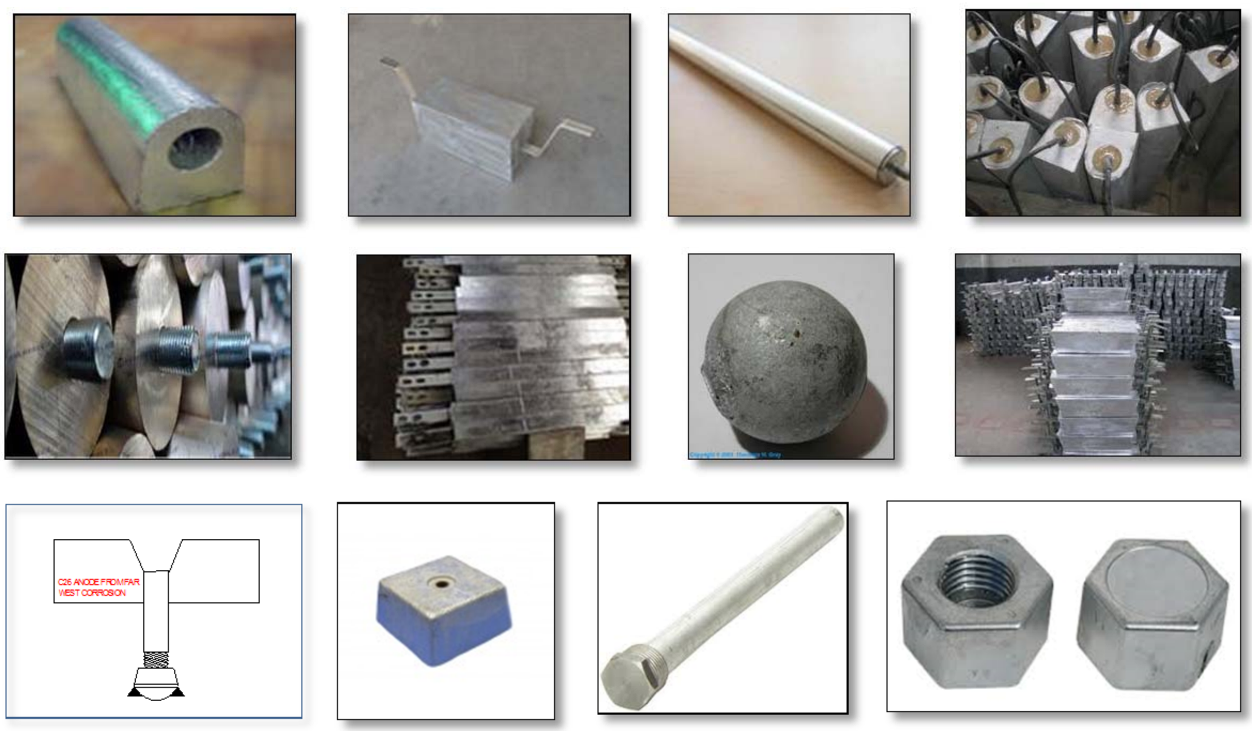
This can also be accomplished using an AC to DC transformer. We call this approach "Impressed Current Cathodic Protections". In this case we select any metallic structure, suspend it in water from the positive pole of our transformer, connect the structure to be protected to the negative pole of the transformer, and turn the transformer up until the half-cell voltage between the structure and the water exceed -850 mv. We need to be careful to control the transformer output to the -850 to -1000 mv range in coated vessels, or we'll drive enough hydrogen through the coating and onto the structure to dis-bond all of the coating! Because of this reality we often steer clear of the impressed current application in the oil industry unless we have corrosion technicians on staff who can monitor and adjust the transformers at least monthly.

ANODES ARE LINE OF SIGHT

In DC current flow electrons flow in a straight line, almost exclusively. That means that if you were an anode trying to protect a structure, and you couldn't see the entire structure, this anode *would not protect it! The savvy corrosion engineer needs to keep this in mind, locating anodes so that each nook and cranny of the entire water exposed structure can be "seen" by its protective anodes. And since water is the electrolyte through which the electrical current flows, each anode MUST be located in the conductive water, and not in the dielectric (non-conductive) oil or in the non-conductive gas space.*

In the real world of cathodic protection we use lots of different sacrificial anodes. They come in many forms and shapes, and several metal alloy formulations. Some are bars. Others are balls. Still others are blocks. Some are small while others are large. Each is available to the corrosion engineer or end user who can select the ones that fit his application best.

Anodes can be cast in virtually any shape or form. Here are a few of the more common examples:



Because of this the corrosion engineer has a limitless selection, and can fine tune any cathodic protection challenge into a corrosion prevention success.

In many oilfield cathodic protection applications we use Victaulic coupled anodes. These anodes are cast into a Victaulic fitting so they can be inserted into a Victaulic connection on any vessel. Once inserted these anodes are clamped in place with a pressure sealed Victaulic clamp like the one pictured upper-right.

They Victaulic coupled sacrificial anodes look like the pictures at the right.

These are available from cathodic protection specialty firms like Far West Corrosion, and others (see:http://www.farwestcorrosion.com/deck-mount-insulating-supports-for-galvanic-anodes.html).

In smaller vessels and compartments we often use block-type anodes. These are cast onto ¾" or 1" pipe nipples for ease of installation onto couplings or Thread-o-lets installed in strategic locations inside vessels.

Anodes have a predictable life. The corrosion rate of sacrificial or impressed current anodes is measurable and totally predictable. When anodes are installed in uncoated vessels they must protect the entire water wetted metal structure. This requires more current flow from the anode to the structure. This is measurable. And, more current flow means faster anode corrosion/deterioration which translates to shorter life and the need for more frequent anode replacement. However, when anodes are applies in coated vessels they only protect the uncoated areas, which initially are the small coating imperfections called holidays. This means the anodes have a considerably extended life. Then, as the coating deteriorates over time, and more and more of the structure is uncoated, the anodes protect the structure with higher and higher current flow, shortening their overall life, but protecting the structure in the interim.

THE USE OF BOTH COATINGS AND ANODES

From the above it may now be clear that the ideal solution to stop corrosion in its tracks it the internally coat the structure and to augment this effort with the application of cathodic protection using either sacrificial anodes or impressed current cathodic protection systems.

When this approach is chosen and properly applied we can rest assured that we have corrosion under control. "Properly" means we need to pay attention to the needs for proper metal preparation prior to coating, stick to the manufacturers' recommended practices for applying their coating, and use industrywide standards for selecting and locating the right anodes in the right places for the job at hand. Then, we need to follow up with routine checks (at least four times a year) of the anode functions to make sure all is well, and with physical coatings inspections and repairs every few years.

CHEMICAL CORROSION INHIBITORS

Chemical corrosion inhibitors are routinely applied in oilfield environs in an effort to mitigate corrosion. These can be particularly effective at controlling corrosion in downhole tubulars, and in internal corrosion control in pipelines, but not so much in surface facilities like separators, FWKOs, heater treaters and tanks.

The chemicals are formulated to find the surfaces of steel and to coat those surfaces with a molecular layer that isolates the corrosion cells from the electrolyte (water). They function well inside tubulars when the flowing fluids are treated with an adequate concentration of the *corrosion inhibition chemical and where fluid flow is often turbulent, exposing a large proportion of the treated flowing fluid to the surfaces of the steel.*

However, as fluid velocities slow down, as they do in our process equipment (so it will function to separate), the opportunity for the chemical corrosion inhibitor to be exposed to the ID of vessels is diminished both by the reduced turbulence, and by the reality that most fluid flow converges into the center of the process vessel where it is farthest from the corroding vessel shell. Additionally, corrosion cells in process and storage vessels are most aggressive when they exist under a layer of sediment, scale, or disbanded coating where the corrosion cell is effectively isolated from the treated flowing fluids.

While this industry spends millions of dollars annually in an attempt to protect surface process facilities, experience shows that most if not all of this money is wasted. Surface facilities need coatings and cathodic protection (anodes) instead!

DOING IT RIGHT

All good project managers share a common philosophy; "The devil is in the details!" This is never truer than it is in the field of corrosion mitigation. Since corrosion is a science we have a professional society to lean on for help. It is focused entirely on corrosion, and is called the National Society of Corrosion Engineers or NACE (see: http://www.nace.org/home.aspx). Every oil company should be represented in NACE, and at least one person should be NACE certified as a corrosion engineer to make sure each effort to mitigate corrosion is done right!

When this isn't possible we should solicit the assistance of NACE certified personnel in vendor firms. These experts can specify, select, and design the placement of anodes in each application, and can address proper metal preparation specifications for coating applications, and even the most ideal protective coating for each case. They can even specify inspection methods and frequencies, making sure we get it right, and keep it that way.

CONCLUSIONS

Corrosion mitigation is a science. It is a profession, not black art. To protect surface process facilities from corrosion we need to apply protective coatings AND cathodic protection to get the best results. Chemical corrosion inhibitors applied to surface process equipment are marginally effective at best.

If you need help, call us!

ABOUT BREAKTHROUGH ENGENUITY AND ITS OWNER/INVENTOR

Bill Ball is the founder and owner of Breakthrough Engenuity LLC. He has a distinguished history of oilfield separation system designs, and a comprehensive list of related patents. Bill's hands-on oilfield experience and career portfolio make him *one of the industry's leading separation authorities today. After his university studies he launched his career in a 1,000,000 b/d waterflood operation where he was responsible for the evaluation and performance improvement of all surface facilities. He joined NACE and SPE. He sent most of his work days crawling through the process equipment of the day, making improvements wherever possible.*

This hands-on experience was the foundation Bill needed to improve, develop, and advance the technologies necessary to improve process equipment efficiencies across the board. In the early years Bill learned what works, and what doesn't! In the decades since his accumulated separation knowledge and experience led to his ten patents, each of which speaks for itself.

The result is a unique approach; one where, "Engineering meets ingenuity!"

Bill's efforts continue to innovate improvements like the patent pending combination free water knockout- heater treater in one vessel. It's called "KOTREAT®". Each new KOTREAT® eliminates the time and expense of installing two more traditional and separate vessels; the FWKO followed by a heater treater, combining the two vessels into one. Through this unique approach and the use of more efficient internals, KOTREAT® has become another industry game changer.

Another example of ingenious innovation is the MorOil™ system. MorOil™ is a patent pending system designed to condense the valuable C4+ hydrocarbon liquids from produced natural gas streams to generate a larger produced oil stream with added cash flow without the need for compression or chilling.

These are just a few of Breakthrough Engenuity's unique oil industry contributions.

Today, Breakthrough Engenuity is one of the industry's leading low-cost engineering and vessel design firms. We specialize developing designs for the industry's most efficient high and low pressure, two and three-phase heated and unheated separators, as well as providing general engineering services geared to specialty subjects like:

- *Optimized tank battery design.*
- *Natural gas handling to optimize income and liquids recovery.*
- *Correct and proper line sizing avoiding turbulence, erosion-corrosion, and eliminating the mixing energies that can create severe emulsion issues.*
- *Specialty vessel internals designed to maximize separation performance.*
- *Recommendations for the optimized application of oilfield chemicals to reduce cost and improve performance.*
- *3D modelling to avoid costly facility installation delays.*

Now, more than ever, Breakthrough Engenuity can be found in every sector of the oil and gas industry, adding cash flow to operators and efficiency to their operations. We're a full service engineering firm. We pledge to meet and exceed every client expectation.

Breakthrough ENGENUITY

CONTACT US

If all else fails, or if you just have a question, don't hesitate to call Bill Ball at Breakthrough Engenuity for assistance. You can reach Bill at the office at 918-298-6841, or on his cell phone at 918-231-9698.