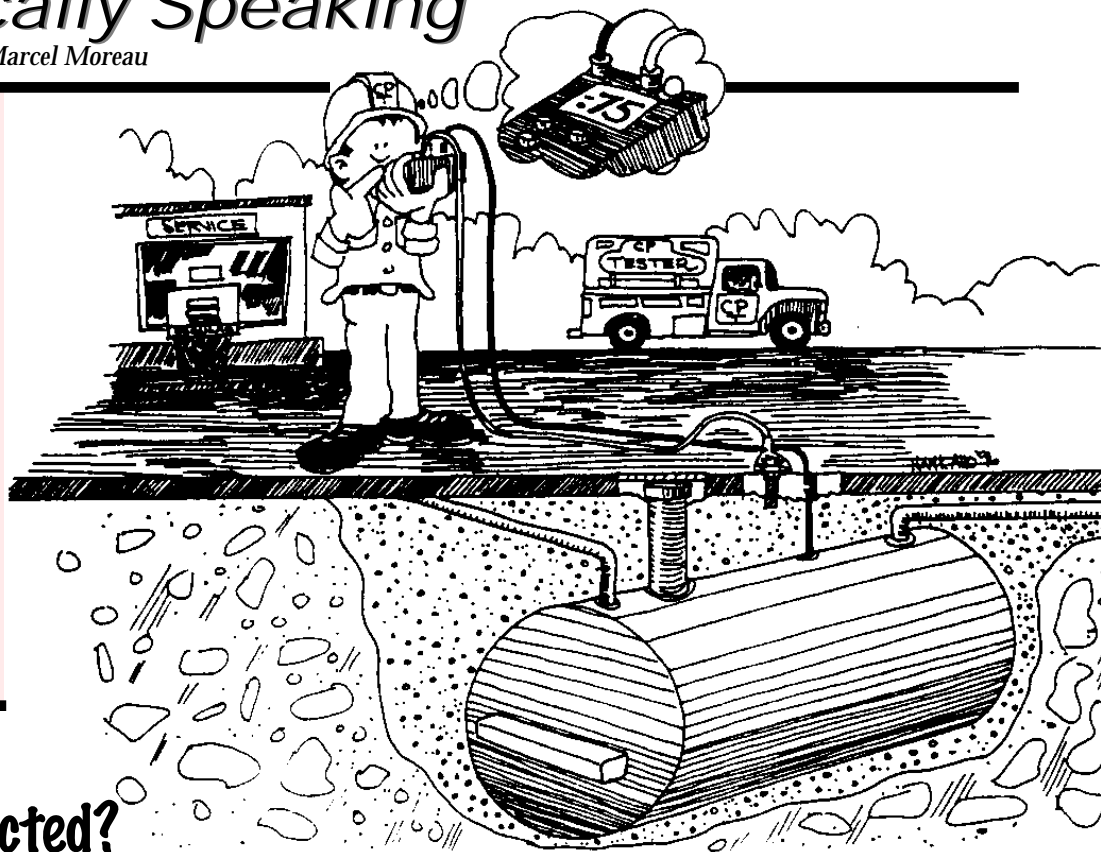


Leak Prevention

Tank — nically Speaking

by Marcel Moreau

In this edition of "Tanknically Speaking," David McCaskill, who writes our "Tanks Down East" column, and Marcel Moreau, who regularly writes this column, have collaborated to discuss some of the problems associated with cathodic protection testing. It behooves anyone who has not read "Rust Though Art And To Rust Thou Shalt Return" in LUSTLine Bulletin #23 to do so before reading this article. Some background on cathodic protection will make this reading more meaningful. Marcel Moreau is a nationally recognized petroleum storage specialist. David McCaskill is a petroleum storage specialist with the Maine Department of Environmental Protection.



Is This Tank Cathodically Protected?

by David McCaskill

Delbert has had cathodically protected (CP) tanks at his station for 8 years and has yet to have them tested to see if they are, indeed, cathodically protected. Federal law requires that galvanic corrosion-protected systems like Delbert's be monitored within 6 months of installation and every 3 years thereafter. Now that the environmental regulatory agency has sent him a letter stating this fact and reminding him that he is in violation of the environmental regulations if his CP tanks haven't been tested, Delbert looks up the name of the guy his installer gave him 8 years ago. Delbert has had enough experience with the flatlanders from the capital to know that this letter is a harbinger of inspectors to come. He also knows that when his tanks were installed, his contractor gave him the low down on how his tanks were protected from corrosion holes. Delbert can see the wisdom of getting a CP tester over to see if everything really checks out.

Charlie, the CP tester, arrives with all the proper paperwork needed to document this blessed event. He brings out his magical meter and hooks one wire to what Delbert knows is his CP test station (a wire connected to the tank) and another wire from the meter to some sort of a probe. He pours water on the soil over the tank ends. He mashes the probe into the ground and peers deep into his meter as if to summon the CP spirit of the tank.

But Charlie's characteristic cherubic smile is soon replaced with a look of bedeviled puzzlement. He mashes the probe into other parts of the soil above the tank, as if dowsing for water. He borrows Delbert's dipstick, fastens a bolt with a wire attached to the bottom end, and lowers the apparatus down the fillpipe. He connects the wire from the dipstick to the voltmeter and peers at the meter again. Still not satisfied with the readings he's getting on his meter, he unhooks the lead to the test station and starts touching the vent pipe and some exposed electrical conduit as if to summon their opinion on the situation. But Charlie has performed CP tests often enough to know that he will have to tell Delbert what he surely doesn't want to hear, that his tank is not protected against corrosion.

Since 1986, Maine's rules have required that CP tests be made every year, rather than every three years, as required in the federal rules, either by a certified installer who has been trained by the Maine Department of Environmental Protection or by a cathodic protection tester. Two years ago our office sent out notices to owners of CP tanks to remind them about our annual CP testing requirements. We included sample CP recordkeeping logs in the mailing. We also sent these notices to our certified tank installers who would be getting the calls to do the work. Once these letters went out, many of the CP installation sins of the past came to light.

The galvanic CP steel tank design relies heavily on isolating the tank from other metallic structures, such as steel piping or electrical conduit which may overwork the CP system. Remember, the CP system was designed to protect only the defects in the tank coating. Isolation is accomplished by providing dielec-

tric bushings (usually made of nylon) at the tank openings. Failure to achieve isolation is the first issue that must be investigated when the CP readings don't meet the specs.

The CP tester in the illustration on page 12 is coming up with a reading of -0.75 volt, which is below the acceptable -0.85-volt level but still well above the naturally occurring reading of a bare steel tank (-0.4 to -0.6 volt). A voltage reading in this range is a positive sign that the cathodic protection system is operating but trying unsuccessfully to protect more than just the tank.

In the past, when a tank installer would call me with questions about a low CP reading, his (or her) first assumption was that the factory anodes had given out and that it was time to slap on a couple of 17 pound magnesium anodes and be done with it. I'd have to tell him that the answer was not necessarily that simple. He'd need to troubleshoot the system to be sure that the tank was, in fact, isolated from all other buried metals. (See Marcel's "How To..." section to find out how this is done.) If the tank is not isolated, then adding anodes will only defer the problem to another not-too-distant time.

Isolating the Problem

We had a rash of reports of low readings soon after our compliance letters went out. It seems that several of our CP testers were running across double-walled CP steel tanks with readings in the -0.6 to -0.7-volt range. The case was cracked when one installer figured out that the leak detection system used to test the interstitial space (the area between the two tank walls) was actually the source of the problem.

Most double-walled steel tanks have an attached 1.5-inch steel monitoring pipe that runs from the bottom of the interstitial space to the surface of the ground. Leak detection probes are placed in the bottom of the pipe where they can detect any leaks. A type of leak detection system popular in Maine uses a probe that senses changes in pressure resulting from changes in the level of the liquid in the bottom of the tube. These pressure changes are communicated to the alarm box by copper tubing that runs from the bottom of

the monitoring pipe, up through the top of the monitoring pipe, then underground to the building where the alarm box is located. The copper tubing exits out of the monitoring pipe through an isolating fitting, but if it touches the inside of the monitoring pipe, the copper tubing and everything the tubing touches becomes, inadvertently, part of the tank's cathodic protection system.

When everything is electrically connected in this way, the anodes on the tank are trying valiantly to protect not only the tank but also the buried copper tubing and any other buried metal structures—plumbing, rebar in the concrete foundation, buried electrical conduit (you get the picture)—caught up in this vast electrical web. This problem is easily fixed by sleeving the copper tubing in small diameter PVC pipe so it doesn't touch the sidewalls of the monitoring pipe. Once this was done, our CP testers found that their readings quickly came up to spec. Needless to say, after that discovery I was a hero many times over. I simply disseminated my acquired wisdom when the subject of low readings on double-walled steel tanks was brought up, saving the contractor the agony of further troubleshooting.

Of course, lack of isolation is not the only possible cause of low readings, but it is the most common one. Very dry soils and spent anodes are also possible causes.

More is Not Better

Several years ago, a large heating oil jobber in our state tested the CP tanks of an industrial client. At this site, the jobber was getting readings that were too high. Now, where cathodic protection is concerned, more is not always better; the readings this tester was getting on these tanks were in the -2.0+ range and fluctuating. But such readings are no mystery to a corrosion expert when he knows that the industrial client is in the business of welding together steel beams.

When a piece of metal is electrically welded, a current must pass from a grounded welding machine, through the welding rod, to the metal, which is also grounded so the current can flow back through the earth, thus completing the circuit. But some of the current sometimes

goes astray through the ground, striking other objects, like buried tanks. So the high readings that our CP tester encountered here were not from the tank's anodes but from the welding machine.

According to a corrosion engineer, the fix to this particular problem is to install a plastic vertical liner between the welding machine system and the tank to block the stray currents from affecting the tank. Of course, a better solution is to not install a CP tank in this kind of environment in the first place—a fiberglass, composite, or jacketed-steel tank is more appropriate. According to the installer, the client was given the fiberglass tank option; however, the low price of the CP tank and the client's affinity for things made of steel won the day. So, before buying a CP tank, check for possible sources of stray currents. If it's too late, then call a corrosion expert. (Contact NACE at (281) 492-0535 ext. 214 for a list of qualified corrosion professionals in your area.)

Other sources of stray currents include electric bus or subway systems, communication towers, or even adjacent impressed current cathodic protection systems protecting buried gas mains or other USTs.

Disappearing Anodes

During the first season of our cathodic protection compliance campaign, a coastal sewer district had the CP tested on an emergency generator tank at one of its coastal lift stations in close proximity to a salt marsh. The reading came in around -1.1 volts that year, but the next year, when the sewer district attempted to start the generator up for its own annual testing, it got a good dose of salty groundwater rather than its normal diet of diesel fuel. The tank was removed, and a couple of good-sized holes were found near the bottom. There was no sign of the anodes.

Several things could have gone awry here. First, the CP tank had been installed in a very aggressive environment. The groundwater in this area was affected by the ocean; it had a high salt content and would fluctuate with the tide. This made the electrolyte of our corrosion cell very conductive, meaning that the CP system would work very effectively but

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also that the anodes would be used up faster. Again, a corrosion-protected fiberglass, composite, or jacketed-steel tank would have been a more corrosion-resistant solution in this location. Second, it is possible that the anode used in this early design was magnesium, which is not suited for saltwater environments. For this reason, zinc anodes are used on ship bottoms to fight the effects of saltwater corrosion.

There is still the disturbing question of why the tank had a passing reading one year and holes the next. There was no evidence of the anodes during the excavation, but then again, we're not talking about an archeological dig here either, so who knows if anything was left of them or not. I say "disturbing" because this means that a) the anodes were not protecting the whole tank, b) the anodes quit working and the holes were formed in less than a year, or c) the CP readings from the prior year were incorrect. Based on the contractor's prior experience in CP troubleshooting, I believe the initial readings were

Most cathodically protected USTs are sold as pre-engineered packages, based on the assumption that one size fits all. These systems have been around since 1969, but until about 10 years ago, they were not installed in very large numbers. As this population of tanks ages, it will become increasingly important to monitor the effectiveness of their corrosion protection to avoid repeating the corrosion problems of the past.

indeed correct. I might also add that the tank in this story was not a sti-P3® tank, which is the industry standard for pre-engineered cathodically protected tanks.

Time And Testing Will Tell

As you can see from my smattering of stories, there are a lot of things to consider when installing and testing cathodically protected UST systems. There are some sites in this state where installers have completed all

troubleshooting and still can't get good readings on tanks less than 10-years old in relatively noncorrosive backfill. Jacketed tanks with a steel inner shells and polyethylene or fiberglass outer shells that provide corrosion protection for the inner steel tank have become popular in Maine at the expense of CP steel.

Cathodic protection has had a long and successful track record in the protection of such steel structures as ship bottoms, cross-country buried pipelines, buried and submerged bridge supports, and oil terminal tank bottoms. Most of these CP systems have site-specific designs and are for the most part tested and maintained by corrosion technicians.

Most cathodically protected USTs are sold as pre-engineered packages, based on the assumption that one size fits all. These systems have been around since 1969, but until about 10 years ago, they were not installed in very large numbers. As this population of tanks ages, it will become increasingly important to monitor the effectiveness of their corrosion protection to avoid repeating the corrosion problems of the past. ■

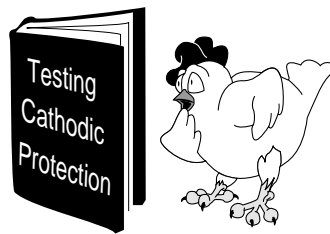
Testing Cathodic Protection Systems

by Marcel Moreau

As David pointed out in the first part of this article, testing of cathodically protected structures is not always straightforward and does not always have the desired outcome. I had similar experiences this fall while teaching corrosion/cathodic protection courses across the country. It is clear to me that testing cathodically protected structures is rarely a "cookbook" type of procedure. A clear understanding of cathodic protection principles is a prerequisite for the correct execution of the monitoring procedure and reasonable interpretation of the monitoring results.

Having said that, I hereby offer my recipe for monitoring the status of a cathodically protected UST system. My goal is not to turn any casual reader into a cathodic protection tester but to provide some guidance for those who need a refresher. An understanding of how the monitoring procedure should be carried out may also help regulators and storage system owners understand what's what when they are reviewing cathodic protection monitoring reports.

As always, comments on how this recipe can be improved are welcome.



Testing Galvanic Cathodic Protection Systems

Equipment Needed:

■ A voltmeter with at least 10 megohm (million ohms) input impedance. Most voltmeters with a digital display will meet this requirement. Although a model from a consumer electronics store will give accurate readings, a voltmeter specifically intended for cathodic protection monitoring will likely be more durable in the field environment.

■ A copper/copper sulfate reference electrode (also known as a "half-cell" or "reference cell"). Typical reference electrodes are about 1 inch in diameter and 6 inches in length. They may have either a flat or a cone-shaped, porous ceramic tip at one end that is covered with a plastic cap. The cap must be removed when cathodic protection measurements are conducted, but it

should be kept in place on the reference electrode whenever it is not in use to minimize evaporation of the copper sulfate solution inside the electrode.

Maintain the reference electrode as follows:

- Keep the reference electrode about 3/4 full with distilled water.
- Be sure that undissolved copper sulfate crystals are always visible inside the reference electrode.
- Discard the solution inside the reference cell when it becomes cloudy. Refill the reference cell with copper sulfate crystals and distilled water. Clean the copper rod with nonmetallic sandpaper.
- Keep the reference cell away from freezing temperatures so that the copper sulfate solution does not freeze, or use the copper sulfate anti-freeze solution provided by the half cell manufacturer.

■ Two test leads (plastic coated wires with fittings on the end) that plug into the voltmeter and can be clipped onto the reference cell and the structure being monitored. Test leads can be any length; however, 2- to 3-foot lengths are typical. It is also a good idea to have a 20- to 30-foot length of wire handy, in addition to the two test leads for field work.

■ A standardized form that can be used to record pertinent information concerning the facility, sketch the facility, note voltage readings, and indicate the locations where voltage measurements were made.

Testing Procedure:

1 Determine how you will obtain an electrical connection with the structure that is to be monitored. If you are monitoring an sti-P3® tank, there may be a monitoring wire (usually green in color) coming up out of the ground and attached to the submersible pump riser, the automatic tank gauge riser, or the fill pipe riser (“riser” is a generic term for a vertical pipe attached to the top of an under-

The purpose of monitoring is to ensure that the entire tank is protected. This means that the portion of the tank farthest away from the anodes must still meet the criteria for protection. It is good practice to take voltage readings with the reference electrode in as many locations as practicable.

ground tank), or located in a special cathodic protection test station. If no wire can be found, see the “What If...?” section that follows.

2 Determine where you will place the reference cell. The reference cell must be in contact with clean, moist soil, not with concrete or asphalt. See the “What If...?” section that follows if no clean soil is accessible. The ideal location is along the top middle of the tank. On many tanks installed after 1990 or so, this is where the automatic tank gauge riser is located and where soil is usually accessible. Other possible locations are around the submersible pump or, if a spill containment manhole has not yet been installed, around the fill pipe.

The purpose of monitoring is to ensure that the entire tank is protected. This means that the portion of the tank farthest away from the anodes must still meet the criteria for protection. Sti-P3® tanks of 10,000 gallons and less have anodes located on the ends; this means that the reference electrode should be placed at the top middle of the tank. Readings taken with the reference electrode placed near the ends of the tank will be higher. If there is no access to soil over the top of the tank, see the “What if...?” section that follows.

It is good practice to take voltage readings with the reference electrode in as many locations as practicable. I have seen tanks where one end of the tank registered 0.95 volts, the middle registered 0.88 volts, and the other end registered 0.83 volts. This situation could

result from an actual deficiency in the cathodic protection caused by significant coating damage at one end of the tank or failure to unwrap the anode at one end of the tank. This deficiency could not have been discovered if only a single reading had been made at the middle of the tank. Note, however, that this situation could also result from petroleum contamination in the soil where the reference cell is placed (e.g., around the fill pipe) or from something that acts to shield the reference cell from the tank (e.g., a metal culvert around the submersible pump).

3 Unless the soil where you intend to place the reference electrode is quite wet, you will need to add moisture. Pour a quart to a gallon of water on the location where the electrode is to be placed and allow the water to be absorbed into the soil before taking the reading.

4 Turn on the voltmeter and watch the display to be sure that it is behaving normally. Consult the meter’s instructions if you don’t know what it is supposed to read when you first turn it on. If your instrument has multiple functions, be sure that it is set to make low voltage DC measurements and that the test leads are plugged into the correct sockets. Connect the positive lead of the voltmeter to the wire from the structure to be monitored and the negative lead from the voltmeter to the terminal at the top of the reference electrode. Do not touch any metal portions of the test leads when making a reading.

The display on the meter should be steady. Fluctuations of 0.01 volt are okay, but fluctuations greater than this may indicate a bad connection. There should be a negative sign in front of the reading, and the reading should be more negative (greater) than -0.85 volts (which is the same as -850 millivolts). Don’t let the negative sign confuse you (-0.90 volts is greater than -0.85 volts [this is what you want]; -0.80 volts is less than -0.85 volts [this is what you don’t

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INTERPRETING WHAT YOUR VOLTMETER IS TELLING YOU

READING	WHAT READING INDICATES
Greater than -1.65 volts for a structure with magnesium anodes	The maximum voltage output from a magnesium anode is -1.65 volts. If your reading is greater than this, the system could have impressed current cathodic protection rather than galvanic, or there could be stray currents in the vicinity. If it turns out this is NOT an impressed current system, have a corrosion engineer investigate as soon as possible.
Greater than -1.1 volts for a structure with zinc anodes	The maximum voltage output from a zinc anode is -1.1 volts. If your reading is greater than this, the system could have impressed current cathodic protection rather than galvanic, or there could be stray currents in the vicinity. If it turns out this is NOT an impressed current system, have a corrosion engineer investigate as soon as possible.
Greater than -0.88 volt	Structure is adequately protected.
-0.85 volt to -0.88 volt	Structure still meets the standard for corrosion protection, but there is not much of a safety cushion. Monitor the system closely to determine the rate at which the voltage is dropping and plan on adding anodes or performing other work on the system in the not too distant future.
Less than -0.85 volt	The structure does not meet the -0.85-volt standard for corrosion protection and is out of compliance with regulatory requirements. This does not mean, however, that the tank is leaking. (See "What if the tank or piping does not meet the -0.85 criterion?" in the following section.)
-0.4 volt to -0.6 volt	Expect this voltage range from steel that has no cathodic protection. This could indicate that the tank was not cathodically protected originally, or that the anodes are completely shot. Call in a corrosion engineer to investigate.
-0.3 volt to -0.4 volt	Rusty steel will sometimes register down in this range. Call in a corrosion engineer to investigate.
-0.1 volt to 0.0 volt	This type of reading is most likely to occur if you are measuring the potential of a piece of copper. Most likely the copper wire you are connected to is broken off underground. Find another way to get an electrical connection to the structure you want to monitor.
Variable readings	This could indicate stray currents, but check your meter to be sure that it is operating properly and that all test lead connections are in solid contact with shiny metal.
Wildly fluctuating readings (digital meter)	This probably indicates that one of your test lead connections is not good or that your reference cell is dry. Make sure that all your connections are solid metal to metal. Might also be indicative of extremely dry conditions in the backfill. Run water from a garden hose into the tank backfill for a couple of hours and take another reading.

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want]). The table on page 16 "Interpreting What Your Voltmeter Is Telling You" should help you interpret your readings.

5 No job is done until the paperwork is completed. While you should document the cathodic protection monitoring with the usual site information (e.g., facility name, address), you should also make a quick sketch of the

layout of the facility and indicate the reference electrode location(s) and the corresponding voltage readings. Duplicating the reference cell locations over time is key to obtaining meaningful cathodic protection data.

What If...?

What if there is no monitoring wire for the tank?

You need an electrical contact with the tank. If the tank is an sti-P3®

tank, all of the risers attached to the top of the tank are electrically isolated from the tank shell and cannot be used to obtain readings of the tank itself. To obtain a reading in this situation, make contact with the bottom of the tank through the fill pipe.

A "quick and dirty" way to do this is to fasten a length of wire (20-foot long or so) to a brass bolt and then fasten the bolt with a stainless steel hose clamp to the end of a dipstick so that the head of the bolt extends slightly beyond the end of

the stick. Clip the end of the wire that is not attached to the bolt to the positive test lead from the voltmeter.

Insert the bolt end of the stick into the fill pipe and press firmly against the bottom of the tank. There may be sludge and scale on the tank bottom which will require firm pressure and a little twisting motion on the stick to obtain good electrical contact. Good contact is indicated by a steady reading on the digital display of the voltmeter.

Be aware, some drop tubes are equipped with tank bottom protectors to prevent any damage that might occur when the dipstick repeatedly strikes the bottom of the tank. The tank bottom protector consists of a metallic plate that is attached to the bottom of the drop tube. A neoprene disc separates the bottom protector and the bottom of the tank, electrically isolating the tank bottom from the tank bottom protector.

Because the tank bottom protector is connected to the drop tube and the drop tube is connected to the fill pipe, the voltage reading obtained through the fill pipe will reflect the voltage of the fill pipe relative to the reference electrode, rather than the tank voltage. So if the dipstick method results in a reading in the unprotected range (0.4 to 0.6 volts) take a reading on the fill pipe. If the fill pipe reading and the dipstick reading are identical and a drop tube is present, remove the drop tube and check for a tank bottom protector before concluding that the tank is not adequately protected.

In some cases, if the tank is equipped with a manway at the bottom of a containment sump, it may be possible to contact the tank shell directly. Look carefully around the manway to determine how electrical isolation is being accomplished and whether any metal connected to the tank shell, or the tank shell itself, is accessible.

What if tank is equipped with a PP4 monitoring station?

If the tank is an sti-P3® tank installed around 1993 or later, it may have a test station consisting of a plastic dome about 3 inches in diameter with five metal terminals imbedded in it that are flush with the surface of

the dome. The central terminal connects to a permanently buried reference cell (you don't need your copper/copper sulfate reference electrode to test this tank), and the four terminals around the center connect to one or more tanks. Simply connect the negative voltmeter lead to the center terminal and the other lead to each of the other terminals on the test station. You should get appropriate readings on as many terminals as there are tanks buried at the facility.

What if I need to monitor piping?

Cathodically protected piping is rarely equipped with monitoring wires to facilitate cathodic protection monitoring, but this is not a serious omission in most cases. Usually, the piping will be accessible at both the top of the tank and beneath the dispenser. There is typically also soil exposed at these locations for placing the reference electrode. If the anodes have been installed as suggested in the Petroleum Equipment Institute's "Recommended Practices for Installation of Underground Liquid Storage Systems" (PEI RP100), the ends of the piping will be the points in the system the furthest away from the anodes and are good places to locate the reference electrode. Be sure that the point of contact between the piping and the voltmeter test lead is clean shiny metal to ensure a good reading.

What if there is no soil along the tank top in which to place the reference electrode?

It is possible to get voltage readings by placing the reference electrode on damp concrete or asphalt, but these readings are generally not considered to be accurate or reliable. In my experience, readings taken with the reference electrode on concrete will always yield a reading in the range of -1 volt, regardless of whether the tank is cathodically protected. Readings through asphalt are unreliable because the voltage is determined by the location of cracks in the asphalt and not the actual placement of the reference cell. The reference electrode can be placed some distance away at the nearest available soil, but

again, this is not the most accurate measure of the corrosion protection status of the tank. In my view, the solution is to drill a hole through the concrete or asphalt to allow direct contact between the reference cell and the soil in close proximity to the tank top.

What if the soil is "dry"?

I often hear that storage systems fail to meet cathodic protection criteria because the tank environment is too dry. While this may occasionally be true in parts of the desert southwest, it is not a likely occurrence in most other parts of the United States. If excessively dry conditions are suspected, run a garden hose to the tank top and pour a large amount of water into the tank backfill.

What if the soil where I need to place my reference electrode is contaminated with petroleum?

Don't take a reading in soil that is saturated with petroleum. Petroleum is not an electrolyte; the reference electrode must contact an electrolyte (e.g., water) for the reading to be accurate. A slight petroleum odor is acceptable for cathodic monitoring purposes, but soil saturated with petroleum will seriously affect readings.

What if the soil is frozen?

Traditional wisdom indicates that cathodic protection monitoring cannot be conducted in frozen soils because ice is not an electrolyte. Experience in Maine indicates, however, that monitoring can be successfully conducted in frozen soils if water is used to dampen the soil where the reference electrode is placed.

What if the tank or piping does not meet the -0.85 criterion?

The most common reason for failure to meet the -0.85 criterion for galvanic cathodic protection is failure to electrically isolate the cathodically-protected structure from other buried metallic or electrical components. The best method for identify-

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ing such components is to measure the voltage of all accessible metal (e.g., piping, electrical conduit, utility piping, leak detection probes). This is done by measuring the tank voltage as described in steps 1 through 5 above and then connecting the negative lead of the voltmeter to all accessible metallic structures *without moving the reference cell*. (This is where that 20- to 30-foot length of wire from the "equipment needed" section comes in handy.) A reading of within a few millivolts of the tank reading indicates that the two structures are electrically connected. The exact place where the two structures are in contact must be located and the connection broken for the cathodic protection to work.

Inadequately isolated tank-anchoring hardware, although a likely source of electrical isolation problems, usually cannot be evaluated using this technique, because the voltmeter connection cannot be made unless the top of the tank is excavated.

Another possible reason for failure to achieve -0.85 volt is excessively dry soil. Refer to the "What if the soil is dry?" section above.

If the tank is isolated and the backfill is damp, but -0.85-volt reading still cannot be measured, research the installation procedures to see if you can discover any clues. Then call the Steel Tank Institute, the tank manufacturer, or a corrosion engineer for help.

Testing Impressed Current Cathodic Protection Systems

Equipment Needed:

The equipment list for monitoring impressed current cathodic protection systems is the same as for galvanic systems.

Testing Procedure:

1 Making an electrical connection to a structure with impressed current cathodic protection is relatively easy; none of the

components should be electrically isolated from one another. The fill pipe or any other accessible tank riser is usually a good place to make a connection to the tank.

One case where this may not be true is when impressed current cathodic protection has been added to a sti-P3® tank. In this case, use the continuity test described under the galvanic cathodic protection question "What if the tank or piping does not meet the -0.85-volt criterion?" to check to be sure that all metallic components of the system are continuous. Use the dipstick method described under the question "What if there is no monitoring wire for the tank?" to check the voltage of the tank shell.

2 The guidelines for placement of the reference cell are basically the same as for galvanic systems. The reference cell should be close to the structure being monitored and as far away from the anode locations as possible. Anode locations can often be inferred from saw cuts and small areas of patched asphalt or concrete. Anode locations should also be indicated on the cathodic protection design documents.

3 The soil where the reference electrode is placed should be wet as for galvanic systems.

4 Test lead connections and voltmeter settings are also the same for impressed current systems as for galvanic systems.

5 The 0.85-volt criterion most commonly utilized for galvanic cathodic protection systems can be applied to impressed current systems but is not considered the most effective for these systems. There are many differing opinions among corrosion engineers as to the best technique for monitoring the effectiveness of impressed current systems. The 100 millivolt (0.1 volt) polarization decay criterion that is described here is included in the National Association of Corrosion Engineers' RP-0285-95.

The set-up of the monitoring equipment (reference electrode, voltmeter, and test leads) is the same as for galvanic monitoring. What is monitored, however, is the change in voltage of the structure that occurs after the power to the rectifier is shut-off. This procedure requires two people to execute it properly: one person to switch off the rectifier, and the other to monitor the change in voltage of the underground storage system.

When the power to the rectifier is interrupted, there will be an immediate drop in the voltage reading at the tank, followed by a continuing slow decline in the voltage. The person monitoring the voltmeter must note the voltage reading immediately after the power to the rectifier is interrupted. (If the meter is digital, the numbers will change rapidly. The reading you want is the second number that appears on the meter's display.) The voltage is then monitored for several minutes (possibly much longer in stubborn cases) with the rectifier turned off. The criterion for cathodic protection is a voltage shift of at least 0.10 volt from the initial reading after the power to the rectifier is cut off. For example, a system might have a voltage of -1.1 volts with the power to the rectifier turned on. Immediately after shutting off the power to the rectifier, the voltage might drop to -0.83 volt. The voltage must then drop below -0.73 volt ($0.83 - 0.10 = 0.73$) to meet the criterion for effective cathodic protection.

Another way to determine if this criterion for cathodic protection has been met depends on whether the original voltage of the tank (i.e., before any cathodic protection was applied) is known. If the voltage reading immediately after the rectifier is turned off is at least 100 millivolts more negative than the original unprotected voltage, then the 100 millivolt criterion has been met. ■

Do not forget to restore power to the rectifier before you leave the site!