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Comments and suggestions are welcome and may be directed to John T. Quigley, Project Director, 432 N. Lake St., Madison, WI 53706. Tel 608-265-2083. To comment on an article, or to suggest topics for *UTTU*, please e-mail Pat Dutt or call 607-272-3212.

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Smart pump-and-treat for MTBE contamination

MTBE was detected in a major public water supply field in Riverhead, Long Island, in June 1995. Further investigation revealed two 3,800-foot-long plumes of MTBE with concentrations in excess of 2,000 ppb. New York State's maximum contaminant level (MCL) for MTBE is 50 micrograms per liter (µg/l).

Regulators decided to pursue a smart pump-and-treat strategy, which according to Hoffman (1993 in Haas and Sosik, 2001) consists of the following steps:

- characterize, in detail, the geology, hydrology and chemistry
- use computer-assisted data interpretation, data display and decision support systems
- remove contaminant sources, if possible
- create an initial design for plume containment and source remediation
- phase in installation of the wellfield
- monitor, in detail, the remediation process
- re-evaluate the operating wellfield, including redesign as appropriate (dynamic management)
- reinject treated groundwater to speed contaminant flushing
- designate appropriate cleanup levels

Hydrogeologic setting

This area of Long Island, New York, "is characterized by a mass of unconsolidated deposits that lie unconformably over southward-dipping crystalline bedrock. The stratigraphic sequence includes three major aquifers and two confining layers" (Haas and Sosik, 2001). According to the borehole logs for the first 40 to 50 feet below ground level, sediments are very fine to medium sand and silt. At 60 to 70 feet, a discontinuous clay-silt layer occurs. Groundwater is found at approximately 18 feet below grade at the north end of the site to about 10 feet below grade near the wellfield. Groundwater direction under static conditions is south at a gradient of 0.085 to 0.1ft/100 ft.

Existing wells

Three municipal wells, drilled into the water table aquifer, ranged in depth from 105 to 140 feet. They were constructed of 16-inch-diameter steel casing with 20 to 30 feet of 16-inch stainless steel screen and produced 3,744,000 gallons per day.

Site investigation

An initial investigation of the RWD (Riverhead Water District) distribution system showed one well in the vicinity of the screen contained MTBE at 240 mg/l. Another well showed that contamination of 12 mg/l, but adoption of a non-detect policy prompted the regulating agency in July 1995 to remove from service both this well and the other one. The DEC developed a plan to limit use of the wellfield while the plume source was identified and delineated.

Field workers used accelerated site characterization techniques to identify the plume source and delineate the dissolved plume's vertical and horizontal extent. They used an Earthprobe^{R} sampling system to obtain samples and used an on-site Photovac field gas chromatograph to analyze samples. Within the next year, 126 groundwater samples were taken from 103 locations. At the same time, field workers installed 25 multi-level wells (each of which contained 10 to 12 individual sampling points) in hot-spot locations along plume centerlines. The multi-level wells "provided a 'permanent' monitoring network between the source areas and municipal receptors and provided information on the vertical extent and gradient of each plume" (Haas and Sosik, 2001).

Field sampling indicated two separate MTBE plumes. Two retail gasoline stations located approximately 3,800 feet north of the wellfield were identified as the source. "Concentration ranged from a high of 1,800 µg/l at a depth of 45 feet below the water table in the west plume to a high of 800 µg/l at a depth of 35 feet below the water table in the east plume. Both plumes were detached from their respective source areas, indicating that the MTBE had almost entirely leached from the soil. The plumes were plunging at approximately 0.014 ft/ft with distance from the source area, as a result of the vertical flow component imposed by both uniform areal recharge and operation of the supply wells at the southern end of the plumes" (Haas and Sosik, 2001).

Regulators discovered that some remediation (excavation, and sparge and vent) had taken place; however, much impacted soil remained on site. Field workers collected another 68 soil samples from 24 locations to further delineate the two source areas.

Modeling

To better understand the groundwater flow regime and evaluate remedial options, workers entered data into a three-dimensional flow model (MOFLOW) that contained an option for particle tracking. After calibrating the model, they achieved a close match between output data and field data. The calibrated model's predictive capability "was checked by comparing model predictions with final drawdown data from a pumping test, and by matching the predicted path lines produced by particle traces with the configuration of the MTBE plumes. Comparison of results indicated that the model could be used to assist in designing the remediation system" (Haas and Sosik, 2001).

The modeling effort

- facilitated establishment of the capture zone of three supply wells under different demand scenarios
- allowed development of an effective remedial/ protective strategy by the interested parties
- facilitated the use of particle tracking to evaluate feasibility of capturing the MTBE plume with a pumping/injection system

The final design for the primary recovery system consisted of six primary pumping wells and four injection wells.

Implementation of the pump-and-treat

Field workers placed the pumping wells about 650 feet upgradient of the two impacted water supply wells and 180 feet from another well, a location that would intercept the plume's highest contaminant concentration while protecting the closer well. Drillers placed six recovery wells at approximately 100-foot intervals and installed two gravity-fed injection wells on either end. Water was treated by a conventional 4 x 30-foot packed air-stripping column.

Chronic iron fouling and low recharge rates stymied recovery well operations. Thus, wells designed to pump continuously at 25 gpm were modified to cycle off in pairs. In addition, field workers installed two additional injection wells with an overflow connection to an existing road drainage basin. Another three recovery wells were installed to reduce contaminant concentrations in hot spots areas.

System monitoring

Remediators initially monitored the system three times per week to make adjustments in the pump flow rate and in discharge pump timing. They also monitored influent samples obtained from recovery wells using a portable GC, and influent and effluent samples from the air stripping tower. Every quarter, field workers obtained approximately 150 groundwater samples from key locations and analyzed the samples at a laboratory. Wells were also checked for manganese and total iron. The high iron fouling rate required frequent redevelopment of the injection wells and biannual rehabilitation of one recharge sump.

Modeling results and closure

Using the transport model BIOSCREEN, remediators determined that the MTBE concentration reaching the river would be less than half of the drinking water standard concentration. Based on these modeling results, other results that assessed "peak" concentrations, and on confirmatory groundwater sampling, the consultant recommended termination of the recovery system after nine months of operation.

Haas and Sosik (2001) asserted that "The success of this project can be attributed to following the key aspects of the nine points described by Hoffman, which included a thorough three-dimensional site characterization, computer-assisted design of the pumping/injection system layout, 'dynamic management' of the remediation effort and use of conservative transport modeling in determining that appropriate cleanup levels have been achieved. This case study demonstrates that when applied properly, the use of "pump-and-treat" technology can be an effective method for remediation of recalcitrant groundwater contaminants such as MTBE."

Reference

Haas, J.E. and C. Sosik, "Smart Pump and Treat Strategy for MTBE Impacting a Public Water Supply Well Field," in *Proceedings of the 1998 Fourteenth Annual Conference on Contaminated Soils*, University of Massachusetts, Amherst; ISBN 1884-940-22-6.

UTTU thanks Joseph E. Haas II, New York State Department of Environmental Conservation, Stony Brook, New York, for his help on this article.

Quantifying microbial sulfate reduction using push-pull tests and isotope analyses

Schroth and others (2001) performed several push-pull tests and stable sulfur isotope analyses in a monitoring well of a petroleum-contaminated aquifer in Studen, Switzerland. Tests performed involved

- evaluating sulfate transport behavior
- injecting anoxic test solutions that contained bromide as a conservative tracer and sulfate as a reactant

Microbial sulfate reduction and stable isotope analysis

"Microbial sulfate reduction is an important metabolic activity in many petroleum hydrocarbon (PHC)-contaminated aquifers. During dissimilatory sulfate reduction, bacteria reduce sulfate (SO_4^{2-}) to sulfide (S(-II)), defined here as the sum of H_2S, HS^- and S^{2-}). Consequently, PHC and other indigenous organic compounds are oxidized and often mineralized to carbon dioxide (CO_2) and water. Thus, microbial sulfate reduction contributes to the removal of PHC constituents from contaminated aquifers. Quantitative information on microbial sulfate reduction, however, is needed to assess its contribution to overall PHC removal at a site" (Schroth and others, 2001).

In natural environments, sulfur "consists largely of two stable isotopes: ^{32}S (95.02% natural abundance) and ^{34}S (4.21% natural abundance). Microbial sulfate reduction usually results in significant isotope fractionation, i.e., an enrichment of ^{34}S in unconsumed SO_2^{4-} coupled to an enrichment of ^{32}S in produced S(-II). Sulfur isotope fractionation in groundwater was previously observed in forest hydrology studies as well as in contaminated aquifers, e.g., at a waste disposal site. Thus, sulfur isotope fractionation appears to be a valuable indicator for microbial sulfate reduction in various environments. Unfortunately, little is known about sulfur isotope fractionation in PHC-contaminated aquifers" (Schroth and others, 2001). Researchers here used stable sulfur isotope analyses of "extracted SO_4^{2-} and extracted S(-II) to determine isotope enrichment factors, which served as indicators for microbial sulfate reduction."

Push-pull test

A push-pull test functions in the following way:

- a prepared test solution that contains a non-reactive, conservative tracer and one or more reactive solutes (reactants) is injected (pushed) into an aquifer through an existing well
- an incubation period—rest phase without pumping—ensues
  - indigenous microorganisms consume reactants and generate metabolic products
- groundwater mixture is extracted—pulled—from the same location
- microbial activity rate is identified using breakthrough curves by measuring tracer, reactant, and metabolic concentrations at the injection/extraction well during the extraction phase

Push-pull tests have been used to quantify a number of microbial processes in PHC-contaminated aquifers:

- aerobic respiration
- denitrification
- sulfate reduction
- methanogenesis
- PHC degradation under nitrate- and sulfate-reducing conditions

The procedure has also been useful in assessing spatial variability in aerobic respiration and denitrification.

Problems often encountered when applying this process of quantifying microbial sulfate reduction include

- short incubation periods wherein none of the injected SO_4^{2-} was consumed during the test
- quantitation based on SO_4^{2-} consumption or S(-II) may be obscured by abiotic transformations such as dissolution/precipitation of gypsum or iron sulfide

Site description

Researchers performed their study in Studen, Switzerland, at an aquifer contaminated by heating oil. The aquifer has the following characteristics:

- a thickness of 20 to 25 m
- an unconfined nature
- unconsolidated glaciofluvial outwash existing with interbedded layers of poorly sorted silt, sand and gravel
- a water table at 2 to 4 m below ground surface
- a hydraulic conductivity ranging from 1.0 x 10^{-4} to 9.3 x 10^{-3} m/sec
- a porosity of 0.19
- an average pore water velocity of about 0.4 m/day

Four push-pull tests

Researchers conducted four push-pull tests in a monitoring well located within the contaminant source zone where free-phase PHC was present. Groundwater within this well (as opposed to groundwater in background monitoring wells) is characterized by the following:

- its environmental conditions are reduced
- concentrations of up to 1 mg/l dissolved PHC exist
- dissolved oxygen and nitrate are almost completely depleted
- SO_4^{2-} is partially depleted

Researchers also determined that methane (CH_4) concentrations increased from this well, which gave them further evidence that the monitoring well was in a transition zone because both sulfate-reducing and methanogenic conditions prevailed.

Groundwater samples from the other three push-pull tests were analyzed for the following:

- dissolved O_2
- S(-II)
- ferrous iron (Fe(II))
- SO_4^{2-}
- dissolved inorganic carbon (DIC, sum of $H_2CO_3^-$, HCO_3^- and CO_3^{2-})

Conclusions

Schroth and others (2001) concluded the following:

- loss of S(-II) occurred by FeS precipitation; increased Fe(II) concentrations are commonly encountered within reduced zones of contaminated aquifers, and this often makes S(-II) data useless for quantification of microbial sulfate reduction
- calculated first-order rate coefficients obtained from three push-pull tests varied by less than a factor of

four; researchers attributed this, in part, to groundwater temperature differences between the tests

- variations in other parameters such as substrate concentration and pH may have contributed to differences in measured rates of sulfate reduction between consecutive tests
- using metabolic product formation of S(-II), and DIC was not helpful in determining quantification/verification of microbial sulfate reduction
- using stable isotope analyses of extracted unconsumed SO_4^{2-}, however, did allow researchers to compute enrichment factors that suggested microbial activity was the major mechanism for SO_4^{2-} consumption

Researchers were able to quantify microbial sulfate reduction in a PHC-contaminated aquifer, using sulfate consumption data obtained from push-pull tests. However, they suggest that "Further experiments will be required to interpret, in a more quantitative fashion, computed isotope enrichment factors resulting from microbial sulfate reduction."

Reference

Schroth, M.H., Kleikemper, J., Bolliger, C., Bernasconi, S.M. and J. Zeyer, "In-situ Assessment of Microbial Sulfate Reduction in a Petroleum-Contaminated Aquifer Using Push-Pull Tests and Stable Sulfur Isotope Analyses," *Journal of Contaminant Hydrology*, 2001, Vol. 51, No. 3-4; http://www.elsevier.com/locate/jconhyd.

Horizontal well basics

By Louis Fournier

The environmental remediation industry often uses horizontal wells to access areas that cannot be accessed using vertical wells or trenches. Use of horizontal wells often lends to simplified operation and maintenance of aboveground remedial equipment. The following article describes some common techniques and terminology used by those in the horizontal well industry.

Horizontal wells may be installed using trenching or directional drilling, which are described below.

Trenches produce a "chimney effect", that is, all of the remedial effect of the well is mandated to occur within the trench. This can have advantages where there are multiple stratigraphic layers and the intent of the remedial project is to provide a "control line" or "cut-off wall" against off-site migration. Typically, the distance-of-influence of a trenched horizontal well at the water table is about the width of the trench.

Directionally drilled horizontal wells, as opposed to a trenched installation, generally have a much wider or greater distance-of-influence as measured at the water table. Commonly, the distance-of-influence of a directionally drilled horizontal well will exceed 50 feet on each side of the well, depending on stratigraphy.

With directional-drilling techniques, two types of wells are normally utilized: continuous (two-ended) or blind (one-ended) wells.

Continuous or two-ended wells are installed by drilling from a point on the surface down to a predetermined depth—which is a function of the remedial process to be deployed—then parallel to the water table (generally), then back up to the surface.

Blind or one-ended wells are installed by drilling from a point on the surface down to a predetermined depth and then extending parallel to the water table (or ground surface) without exiting. Whether continuous or blind wells are used, the horizontal section is normally custom-screened. The nature, specific slot size and spacing, well diameter, well materials, and installation methods for the well must be designed properly to meet remediation requirements. Otherwise, the well may fail to achieve remediation purposes. An environmental well that is not properly engineered, installed, developed, operated and maintained wastes time and money.

The distance from the equipment end of the well to the horizontal is commonly called the "head" of the well, while the distance from the horizontal screened segment to the distal end is commonly called the "tail" of the well.

Well vs. a bore

Horizontal wells are screened, bores are not. Horizontal wells are intended to interact with the surrounding formation. Bores are not. The drilling methods used to install horizontal wells are very different from those used to install bores, although the same drill rig may be used for either. The drilling fluids, drill methods, development requirements and other facets of horizontal wells and horizontal well installation are vastly different in many ways from those associated with horizontal bores.

Applicability of horizontal wells

For small sites, less than an acre, and with deep water tables, greater than 50 feet, the use of horizontal wells for groundwater recovery, total fluids recovery, air sparging or biosparging is generally not recommended. The "head" and "tail" lengths required to reach horizontal will not allow the well to be drilled onsite unless the entrance and exit points can be located offsite. Still, a horizontal well could be used on this type of site for soil vapor extraction (SVE).

The larger the site, the greater the likelihood that horizontal wells will be economically and technically favored over vertical wells, especially if buildings and other site facilities or operations exist. Generally, remediators can design horizontal well remediation systems that will not interfere with on-going site operations.

Number of horizontal wells at a site

Universal "rules of thumb" in the environmental remediation industry do not exist; however, more than 200 horizontal well projects, have shown the following to be true:

- a single horizontal well will often cover the same area and provide the same treatment as dozens of vertical wells, depending upon remediation technology deployed
- for air sparge and biosparge applications, a horizontal well will often have a distance-of-influence (DOI) approximately three to five times the radius-of-influence (ROI), as measured at the water table, of a vertical well with the same screen depth
- a horizontal soil vapor extraction (HSVE) well will have a much greater DOI than a horizontal air sparge or biosparge well placed in the same stratigraphy

One-ended wells vs. two-ended wells

Although it is frequently technically possible to install either a one-ended or two-ended well at a site, continuous or two-ended wells offer a number of advantages including the following:

Reduced drilling cost. Depending on the driller selected, a one-ended well can cost more than twice as much per linear foot than a two-ended well. True, the "tail" of the well is not installed with a one-ended well, but a cost analysis still generally favors a two-ended well.

Greater ease of well installation. A one-ended well must be installed from the drill end, a complicated and usually difficult undertaking. A two-ended well can be pulled in from the distal end. This ease of installation usually translates to a greater assurance of project success and reduced overall project cost.

Increased well performance testing flexibility. Commonly, the pressure or flow at the distal end of the well is taken as an indicator of well performance. With a one-ended well, this measurement is not possible.

Greater maintenance flexibility. Horizontal wells and horizontal well systems must be routinely tested and maintained to ensure performance over the full life of the remediation project. Often this involves washing or cleaning debris from the well interior. This step is facilitated with a two-ended well and hampered using a one-ended well.

Improved well development. After installation, a horizontal well must be developed according to requirements of the client, oversight contractor, mud supplier, or regulator. These development procedures are normally easier to undertake and accomplish with two-ended rather than one-ended wells.

Horizontal well design

Horizontal well design factors include the slot size and spacing, distribution of open area along the screened interval, well diameter and other factors. Site stratigraphy and operating requirements will influence these factors. In addition to the engineering design for each well, wells must have a drilling profile or drill path, which cannot be identified until the driller is selected. The need for a specific radius-of-curvature and drill path can influence number of wells drilled and well layout.

Standard well design?

While there is no universally applicable optimum or "standard" design, a popular design employs a 4-inch-diameter HDPE (high-density polyethylene) pipe and 400 feet of screened interval. Longer screened intervals generally require larger diameters. Shorter screened intervals can sometimes be installed with smaller-diameter well materials. While fluid dynamics may predict that a smaller diameter can be used with shorter screen lengths, as a practical matter, use of 4-inch-diameter pipe better supports well maintenance and development options.

Materials used in well construction include stainless steel, carbon steel, HDPE, polyvinyl chloride (PVC), and fiberglass. Each material has advantages and disadvantages. The majority of wells installed over the past 10 years have been constructed of HDPE.

Screen type

Any conventional slotted or perforated well material used in the vertical well industry may be used for horizontal wells, with the following provisions:

- the percent open area of the well material must be appropriate to the well and remediation requirements
- except for very short wells, a single well-screen zone cannot be used successfully to achieve linearity of treatment along the well screen
- uniform screens produce non-uniform treatment destruction; a non-uniform screen must be fabricated
- requirements of percent-open-area distribution along the well screen can be accurately calculated only using computer software programs
- a well screen specified for one particular remediation application, for instance, soil vapor

extraction, cannot typically be used successfully for another remediation application, such as biosparging

In general, large open areas are not beneficial to horizontal wells. The challenge is to obtain uniformity of treatment distribution rather than a screen interval with large open area.

Costs

Costs vary considerably depending on site characteristics, well installation requirements and well design; however, a reasonable well drilling estimate is approximately $100/foot. Other expenses include cost of well materials (approximately 10 percent of drilling costs), waste treatment, oversight, and engineering design (approximately 10 percent of drilling costs).

The total cost of a horizontal well project is frequently half the cost of a comparable vertical well project. If remediators can use biosparge wells instead of pumping-and-treating with vertical wells, for example, a project savings of 75 to 80 percent may be realized.

A single horizontal well with one blower used for biosparging, for example, can replace up to 70 to 80 vertical wells with 7 to 8 blowers (assuming 10 vertical wells per blower). This results in reduced equipment costs, reduced power hookup costs, substantially reduced manifolding on the surface, and reduced O & M costs. Vertical wells are normally very difficult to 'keep balanced'; the horizontal well is self-balancing and self-manifolded. No surface manifolding exists.

Reference

Horizontal Well Questions & Answers, http://www.angelfire.com/biz/horizontalwells/page11.html

See also "Horizontal Wells for Subsurface Remediation," by L. Fournier, *Contaminated Soil, Sediment and Water*, June/July 2001; http://aehsmag.com.

UTTU thanks Louis Fournier, STAR Environmental Inc., for sending us this article.

Controlling galvanic corrosion in soil, part III

By Jane M. Turner

This is part III of a series of articles on galvanic protection. Part I (*UTTU* Vol. 16, No. 3) described the basic concepts of corrosion, while part II (*UTTU* Vol. 16, No. 4) described impressed current systems and anodes, monitoring, backfill material, lead wire insulation, rectifiers and groundbed geometry. Part III continues the discussion by focusing on installation, electrical isolation, electrical continuity, inspection, monitoring and maintenance.

Installation procedures

Once the cathodic protection system design has been accepted by the client, the system needs to be installed. The need for qualified technical supervision or inspection services during construction cannot be overemphasized. All too often a cathodic protection system installed without such supervision or inspection requires extensive post-installation troubleshooting. The hours and money spent investigating and correcting a malfunctioning system will often far exceed the time that should have been spent supervising the installation. Qualified technical supervision during installation will help ensure a properly functioning cathodic protection system.

Scope of work

The inspector will require specific information for system installation. The most useful information is the design report. This report should contain a description of the project background and the rationale used in developing the final design. The following items should be present:

- the contract drawing numbers that were reviewed, and the data on the drawings
- the specifications that were reviewed, and when
- a description of the field tests made, including the procedure by which the tests were conducted
- the field data used for developing the design; to be included in the appendix of the design report, this data will provide information on soil resistivity and chemistry, information essential for making field modifications
- a description of each system evaluated for corrosion control; this would include pipe type and size, linear feet of pipe, selected current density, coating type, isolation requirements, and anticipated coating quality
- existing structures that may be affected by the selected corrosion control system and existing structures that are being cathodically protected

With a well-prepared report, inspectors or supervisors know precisely what to expect in terms of system performance. They will also be able to recognize field conditions that were not considered or anticipated during the design.

Galvanic anode installations

During new construction, galvanic anodes are often selected to provide the cathodic protection. The earth in which the packaged anode is placed will determine the amount of current available from the anode. Galvanic anodes, installed in an electrolyte with higher soil resistivity than anticipated, will not be able to provide the amount of current required to meet the cathodic protection criteria. This situation is typically encountered in areas that are undercut or where footings are installed prior to pipe installations.

Sacrificial anodes must be placed in an electrolyte whose resistivity is within the design tolerances.

Impressed current anodes

Conditions surrounding the installation of impressed current anodes are similar to those of galvanic anodes. The design will be based on the impressed current anodes being placed in a certain resistivity environment, but because the current from impressed current anodes can be adjusted, there is more flexibility. A significant variation in anticipated backfill will, however, affect the required rectifier voltage capacity.

Electrical isolation

Electrical isolation of the structure being protected is often a critical aspect of a cathodic protection installation. Cathodic protection systems are typically designed to protect a finite surface area. This surface area takes into account coating quality and electrical isolation maintenance where needed. Failure to assure electrical isolation will increase the amount of surface area requiring cathodic protection. Galvanic anodes will typically not be able to provide the additional protective current required. Impressed current systems may have sufficient capacity to protect the additional surface area, but the increased current output of the system will have an impact on the system life. Examples of shorted conditions include

- where reinforcing steel contacts under-floor piping risers
- where a cased pipe comes into metallic contact with the casing
- where piping is connected to an electrical ground
- where pipe penetrates walls or manholes and comes in contact with the steel sleeve or reinforcing steel
- at crossings between buried pipelines (often referred to as foreign line crossings)

The possibilities are endless, but if the system is monitored during installation, the existence of such conditions can be detected and corrected before they become a serious problem.

Electrical continuity

Just as electrical isolation is a necessity between protected and unprotected structures, it is usually imperative that the facility being designed for cathodic protection be electrically continuous throughout. Mechanical connections, bell-and-spigot joints, sections of buried pipes or other buried metallic structures must be electrically continuous with each other if they are to be protected. Electrical continuity is usually accomplished by thermite-blazing an insulated conductor between the structures and across each mechanical or bell-and-spigot joint. Failure to ensure continuity will result in pipe that is not cathodically protected or pipe that will suffer accelerated corrosion from electrolytic corrosion.

When designing impressed current systems, the designer must pay close attention to the bond resistance across joints and between structures. Insufficiently sized bond cable can have the same effect as an electrical discontinuity.

During the installation, the installers must conduct continuity tests as sections of pipe are laid and backfilled. Continuity tests during installation will ensure that all improperly bonded joints are located prior to job completion. Discontinuities can be located after the installation is complete, but the task is very time-consuming and expensive, especially if the pipe is under concrete. Requiring heavy equipment to return to excavate open bond wires is frustrating, costly and unnecessary.

Coating inspection

During transportation and handling, pipe coating often becomes damaged. Coating quality is an important parameter of the cathodic protection design and should be specified in the contract documents. If the contractor is unfamiliar with the coating material, the manufacturer of the coating should be required to visit the job site and instruct the workers in the proper procedure for coating joints and repairing coating damage. Valves and other irregular fittings are typically coated with a brush-applied mastic or sprayed with an epoxy coating. The need for proper surface preparation must be emphasized to ensure proper bonding of the pipe coating.

Monitoring test stations

Test stations are installed to facilitate testing of the cathodic protection system. Some uses for test stations are:

- to measure amount of current drain from one structure to the next
- to determine effectiveness of isolating flanges or dielectric unions
- to determine if a cased pipeline is shorted to the casing
- to provide an electrical connection to the pipe for measuring pipe-to-soil potentials
- to measure the current output of galvanic anodes

Test stations are an important part of a cathodic protection installation, and care must be taken to ensure that the lead wires are not damaged during construction. This point cannot be over-emphasized when site construction is underway simultaneously with the cathodic protection installation. Test wires should be protected immediately after installation, otherwise they may require replacement.

Maintenance

After the cathodic protection system has been installed and energized, it must be properly maintained. Maintenance and monitoring will ensure that the system continues to provide the protection needed to mitigate corrosion.

Impressed current systems require more attention than galvanic systems. Rectifiers should be monitored monthly and the voltage and current outputs recorded in a log book. Significant deviations from previously recorded outputs will warrant further investigation. Minor seasonal variations in rectifier output can be expected due to changes in temperature and soil moisture content.

To an experienced technician, many rectifier problems such as blown fuses, loose connections, defective meters and severed groundbed cables are obvious. If the problem is in the rectifier, each component must be systematically isolated until the defective part is located.

With both galvanic and impressed current cathodic protection systems, test stations need to be maintained to facilitate future testing. Abovegrade isolation devices must be maintained so that they continue to electrically isolate the protected structure. Metallic paint should not be used, and pipe hangars must be electrically isolated from the protected structure or placed on the unprotected side of the insulated flange.

All systems should be surveyed annually by a qualified corrosion engineer. The resurvey should accomplish the following:

- check the system for obvious mechanical defects or damage; this includes damaged test stations and rectifiers
- check all accessible isolation devices to be sure they are operating properly; one of the major contributing factors for insufficient cathodic protection levels is defective isolation devices
- record structure-to-soil potential measurements; if possible, the cathodic protection current being applied to the surface should be interrupted to eliminate the IR (voltage) drop; it may also be necessary to conduct depolarization tests to determine effectiveness of the protection system

A report should be submitted with a description of the structure being evaluated, the status of the system before and after adjustments, the test procedures conducted, a copy of all test data and a description of any system components that require maintenance or replacement. Without an effective monitoring program, the continued effectiveness of the cathodic protection system will be sacrificed.

Conclusion

Whether designing a cathodic protection system for an existing or new structure, several field tests must be conducted. Results of these tests and information obtained during conversations with the client will provide the designer with the information necessary to select the required cathodic protection system.

During installation, the system components must be protected from damage. The inspector must assure that all system components are installed where shown on the contract drawings, and as required by the specifications. Revisions to the structure layout may have a detrimental impact on the cathodic protection system design. A qualified inspector will have the knowledge to adjust or modify the cathodic protection system and to perform the annual re-survey work to ensure that the system meets or exceeds the specified criteria.

Summary

Corrosion is a phenomenon that occurs naturally to all metals not in their natural state. Corrosion can be mitigated by installing a properly designed cathodic protection system and maintaining the system. Tests must be conducted to determine which of the two cathodic protection systems, galvanic or impressed, is the best engineering choice.

With proper design, installation and maintenance, a cathodic protection system will extend indefinitely the life of a buried or submerged metal structure.

Reference

Turner, J.M., "Controlling Galvanic Corrosion in Soil with Cathodic Protection," 1988, *Technical Paper Library, CP-17*, Corrpro Companies Inc., Chicago, Illinois.

UTTU thanks J.T. Lary, Corrpro Companies, http://www.corrpro.com, for his help on this article.

Research notes

Degradation of Diesel Oil by Biosurfactant-Producing Bacterial Strains

Jacobucci, D.F.C., Vasconcelos, C.K., Matsuura, A.B., Falconi, F.A. and L.R. Durrant, *Contaminated Soil, Sediment and Water*, August 2001; http://aehsmag.com.

Researchers isolated microbial strains from soil contaminated with diesel oil and tested them with respect to their surfactant properties. The strains cultured included *Acinetobacter calcoaceticus, Flavobacterium, Moraxella nonliquefaciens, Pantoea agglomerans* and

Planococcus citreus. "Surfactants are amphiphilic molecules consisting of hydrophilic and hydrophobic domains, which tend to partition preferentially at the interface between fluids of different polarity and hydrogen bonding...In bioremediation processes, they can promote the biodegradation of hydrophobic pollutants such as hydrocarbons by emulsification and solubilization...The solubilization of hydrocarbons may be restrained by their existence in oil matrix and may be also dependent on the attachment of microorganisms to the oil surface. Thus the direct contact of cells with the surface of oil is thought to be important in the bioremediation of crude oil" (Jacobucci and others, 2001).

Researchers found that the microbial strains grown in various percentages of diesel oil mixtures were, for the most part, able to produce a significant amount of biosurfactant. Jacobucci and others (2001) state that "the biosurfactants and emulsification produced following growth of these bacterial strains in petroleum-derived compounds demonstrate their potential to be used in the bioremediation process."

Earthworms in Crude Oil-Contaminated Soils: Toxicity Tests and Effects on Crude Oil Degradation

M. Schaefer, *Contaminated Soil, Sediment and Water*, August 2001; http://aehsmag.com.

Earthworms are often used to test the toxicity of contaminated soils because of their high biomass in soil and their sensitivity to environmental influences. The purpose of this study was to "assess the toxicity of oil contamination with earthworm toxicity tests...and to analyze the significance of earthworms for the degradation of oil contamination in soil" (Schaefer, 2001). The tests performed included the acute test, reproduction test (ISO 11268-2), and avoidance response test. Results indicated that crude oil at a concentration of 1 g/kg did not have any lethal effect on earthworms; however, a dose response pattern was identified in the reproduction test. "The test organisms responded to the oil contamination by a decrease of cocoon production and, therefore, reduced numbers of hatched juveniles. The avoidance response test also showed a toxic effect, but only at the highest concentration. Earthworms are able to avoid unfavorable surroundings because of their high numbers of chemoreceptors located in the prostomium, which let them react sensitively towards chemical influences...Chemical analyses showed a reduction of the total hydrocarbon concentration during the test duration in variants with earthworms, whereas in controls without worms, no significant reduction was observed. The positive influence of earthworms on the reduction of oil pollution in soil can be explained by better aeration of the soil due to digging activities and the enhancement of microbial activities. Earthworms have a complex interrelationship with microorganisms; they promote microbial biomass and activity in the soil's decaying organic matter by fragmenting it and inoculating it with microorganisms which disperse widely through soils" (Schaefer, 2001). Schaefer also suggests that earthworms be considered as additional agents of bioremediation.

Oleophilic Biofertilizer Based on a Rhodococcus Surfactant Complex for the Bioremediation of Crude Oil-Contaminated Soil

Ivshina, I.B., Kuyukina, M.S., Ritchkova, M.I., Philp, J.C., Cunningham, C.J. and N. Christofi, *Contaminated Soil, Sediment and Water*, August, 2001; http://aehsmag.com.

This bioremedial study of crude oil-contaminated soil took place in the Ural climatic zone, which has a very short warm season—only 120 to 125 days a year. In this climate, natural attenuation of petroleum-contaminated soils is slow, but agrotechnical methods such as tilling, loosening, watering, or addition of straw, compost or mineral fertilizers can reduce contamination by 30 to 40 percent. The high-molecular-weight paraffins—the aromatic and polycyclic compounds (weight percent in crude oil from 20 to 65 percent)—may not be degraded for years. These compounds "bind to the soil particles, producing hydrophobic residues, and become non-bioavailable to microorganisms. To increase the bioavailability of hydrocarbon pollutants, surface-active agents (surfactants) may be used, allowing desorption and solubilization of petroleum hydrocarbons and thus facilitating their assimilation by microbial cells. Synthetic surfactants commonly used for this purpose can be highly toxic and non-biodegradable and may lead to the accumulation of ecologically harmful compounds in soil" (Ivshina and others, 2001).

These researchers used oleophilic biofertilizer—an ecologically safe and effective biosurfactant produced by *Rhodococcus* bacteria—to remediate soil polluted with crude oil of up to 200 g/kg of total recoverable petroleum hydrocarbons (TRPH). Researchers carried out experiments by placing contaminated soils and the surfactant in 8-liter vacuum desiccators to which bulking agents were added. They added the surfactant-based biofertilizer weekly for one month at a concentration of 10 g/l. The soil was tilled and watered to maintain a 20 percent moisture content. Researchers then monitored on a daily basis the temperature and pH of both systems and the dissolved oxygen in the slurry and soil moisture content. They analyzed samples for microbiological and chemical analyses on a weekly basis.

Field tests showed that introducing the biofertilizer significantly increased the number of soil hydrocarbon-oxidizing and heterotrophic microorganisms, leading to a 1.3- to 1.6-fold increase in oil biodegradation rate.

Microbiological studies of the laboratory slurry bioreactor content indicated that initial heterotrophic and hydrocarbon-oxidizing bacteria increased; following biofertilizer treatment, heterotrophic bacteria increased 100 fold, and hydrocarbon oxidizers increased 500 fold. Ivshina and others (2001) report that "each subsequent treatment with biofertilizer led to a 10-fold increase in various groups within the reactor. Field testing indicated that "after 3.5 months of bioremediation using field slurry bioreactor and land farming cells, contamination was reduced to 1.0 to 1.5 g/kg of TRPH. The oleophilic biofertilizer was shown to enhance decontamination of heavily oil-contaminated soils in cold climate regions" (Ivshina and others, 2001).

Information sources

U.S. EPA publications and information

Publications that can be downloaded from http://clu-in.org/techpubs.htm include

- Surfactant-Enhanced Aquifer Remediation (SEAR) Design Manual (TR-2206-ENV)
- VOC Off-Gas Treatment Technologies Database

Videos/presentations from CLU-IN studio:

- ITRC Phytotechnologies
- ITRC Passive Diffusion Samplers
- Remediation System Evaluation and Optimization of Pump and Treat Projects
- Tranguch Gasoline Spill Site

U.S. EPA Web sites

Ground Water Sampling Guidelines for Superfund and RCRA Project Managers (EPA 542-S-02-001), http://www.epa.gov/tio/tsp/download/gw_sampling_guide.pdf

In-Situ Enhanced Source Removal (EPA 600-C-99-002), http://www.epa.gov/ada/research/src_remed2.html

Role of Background in the CERCLA Cleanup Program (OSWER 9285.6-07P), http://www.epa.gov/superfund/programs/risk/role.pdf

Other Web sites and papers

"Fracturing Technologies to Enhance Site Remediation" (TE-02-02), http://www.gwrtac.org/pdf/frac_e_2002.pdf

Horizontal well information

- http://www.angelfire.com/biz/horizontalwells
- http://www.integrityengg.com

"Identifying Critical Parameters for the Johnson and Ettinger Vapor Pathway Model" can be downloaded from the American Petroleum Institute Web site, http://api-ep.api.org/filelibrary/Bulletin17.pdf

ITRC Quarterly Update, http://www.itrcweb.org/ITRC0302Update.pdf

USTfields information, http://www.epa.gov/oust/ustfield

Other information

Analytical Mass Spectrometry: Strategies for Environmental and Related Applications is available from Oxford University Press (http://www.oup-usa.org/), for $125.

UTTU obtained this information from *Ground Water Monitoring and Remediation* (http://www.ngwa.org), *Environmental Science & Technology* (http://www.pubs.acs.org/) *and TechDirect* (http://clu-in.org/techpubs.htm). *UTTU* thanks the editors and writers for allowing us to reprint this information.