MONITORING WELL REHABILITATION AT THE DEPARTMENT OF ENERGY PADUCAH GASEOUS DIFFUSION PLANT PADUCAH, KENTUCKY

T. L. Brindley, J. J. Tarantino
CDM Federal Programs
325 Kentucky Ave., Kevil, Kentucky 42053

ABSTRACT

The purpose of the monitoring well (MW) maintenance implementation plan is to protect and maintain the integrity of the MW network at the Paducah Gaseous Diffusion Plant (PGDP) to obtain representative groundwater samples. Recent downhole investigations at PGDP [1,2,3] indicate that the most common maintenance problems of the MWs are biofouling and corrosion. The recent video camera inspections revealed evidence of active corrosion of the stainless steel casings and biofouling across the intake screens of 75 monitoring wells. This plan combines regular assessment of each well's physical condition and performance along with Blended Chemical Heat Treatment (BCHT™) to control biofouling and microbially induced corrosion within the well screen and casing. This MW maintenance implementation plan outlines MW evaluation methods including downhole equipment examination, video inspection, physicochemical, and historical data and information review. In addition, each phase of the BCHT™ MW rehabilitation method is described.

A schedule to maintain the compliance, surveillance, and water level wells has been developed. Generally, the order of prioritization is compliance wells first, surveillance wells next, and water level wells last. This order was selected based on the fact that compliance wells are sampled for permit and regulatory requirements.

The Waste Management Section summarizes the requirements (regulatory and PGDP specific) and estimated quantities of wastes associated with the implementation of the BCHT™. This section addresses the management of wastes from the point of generation through characterization and disposal. Standard practices and procedures regarding the handling, transportation, and storage of wastes will comply with the Resource Conservation and Recovery Act and the Toxic Substances Control Act.

INTRODUCTION

Purpose

This paper will discuss details about how the Blended Chemical Heat Treatment (BCHT™) process was used for rehabilitation of 89 wells at the Department of Energy Paducah Gaseous Diffusion Plant (PGDP) at Paducah, Kentucky. A summary will be provided of the various types of problems observed in the wells and the benefits resulting from performing the BCHT™ process

The purpose of the maintenance implementation plan is to protect and maintain the integrity of the monitoring well (MW) network at PGDP to obtain representative groundwater samples. This preventive maintenance program combines regular monitoring of the well's physical condition and performance with BCHT™ applied as preventive maintenance or for full rehabilitation. This approach is similar to the treatment being implemented on the extraction wells associated with the Northwest and Northeast plumes [4,5,6].

Strategy

Wells are best maintained by a preventive maintenance program involving routine monitoring of the well's performance along with preventive maintenance and treatment as necessary. The objective of this plan is to develop a treatment and maintenance schedule that addresses wells with known problems first and provides a method to identify and treat problem wells in the future. For example, compliance-driven MWs with known problems are scheduled first. Later, surveillance wells and water-level measurement wells will be addressed based on the results of maintenance monitoring. The schedule will also consider current and projected budgets.

The maintenance schedule will be determined annually based on a review of, and consideration of, each well's depth, the physicochemical parameters (physical and/or chemical groundwater properties) indicative of biofouling, and visual examinations (as recorded in field log books during sampling). However, these methods are only indirect indicators of biofouling and may only show the most significant issues. Consequently, all wells will, at a minimum, be placed on a seven-year rotating schedule for treatment.

Background

The results of three recent downhole investigations at PGDP [BJC 2000a; BJC 2000b; BJC 2001] indicate that the most common problems threatening the groundwater sampling integrity at the PGDP are biofouling and corrosion. The investigations revealed evidence of active corrosion (minor to severe) in the stainless steel casings and biofouling in the screens of 75 compliance monitoring wells.

Biofouling Discussion

Biofouling involves the biological formation and the deposition of fouling materials, which usually include mineral and metal-precipitates [iron (Fe), manganese (Mn), or sulfur (S)] that can be biologically or chemically induced. These complex biological coatings are known as biofilm and are commonly referred to as slime. In groundwater source systems (e.g., PGDP), biofouling usually involves the oxidation or reduction of Fe, Mn, and S compounds by bacteria.

These compounds become part of biofilm complexes including the iron (Fe), manganese (Mn), and sulfur (S) compounds, extra cellular polymers, and bacteria cells themselves. Bacteria utilize substrates such as hydrocarbons in the absence of oxygen through other electron acceptors such as ferric iron (Fe^{3+}), sulfate (SO_4), and nitrate (NO_3). These microbial mediated redox reactions described above can be complex and add greatly to the problem of fully understanding the geochemical environment [7].

Microbiological slime deposits generate an array of problems in MWs at PGDP. Fe and Mn biofouling can vary from a minor nuisance to a major maintenance problem resulting in complete abandonment of MWs. First, the biofilm accumulation in the well screen and the surrounding formation can physically plug a well and the formation. Biofilms eventually grow, expand, and interconnect, thereby reducing the transmissivity of the well screen and porous media. This is referred to as microbially induced fouling. Additionally, microbially induced accumulation occurs as various metallic elements are precipitated or otherwise entrained within the biofilm. This may result in abnormally low metal concentrations in water sampled from the MWs. Alternatively, microbial induced relocation occurs as the biofilm and accumulated metals slough off and are transported in the well, resulting in sporadic or increased metals concentrations. Either phenomenon potentially creates biased or erratic data and raises questions about the analytical data integrity.

Although biofouling can contribute to chemical and biological corrosion of stainless steel well screens, this does not seem to be the case at PGDP. The well screens examined during the video camera inspections appear to be intact and those screens examined in the corrosion study [3] also showed no evidence of corrosion. In addition, two recent MWs abandoned (MW-90 and MW-95) indicated no visual evidence of microbial induced corrosion (MIC) on their respective well screens.

Biofouling affects the well screen and the surrounding filter pack and formation, and based on recent studies it appears to be the result of iron-related bacteria (IRB), sulfate reducing bacteria (SRB), slime related bacteria, and heterotrophic aerobic bacteria (HAB). These bacteria actively grow in the redox environment in the vicinity of the well screen, gravel pack and adjacent formation [BJC 2000a; BJC 2000b; BJC 2001]. Biofouling is a very common problem, particularly in shallow groundwater wells such as those at PGDP. While biofouling cannot be eliminated, periodic treatment along with scheduled maintenance is usually sufficient to control the problem.

Corrosion Discussion

A variety of microbial activities and products contribute to corrosion of stainless steel. Corrosion can be defined as the deterioration of material by reaction to its environment. Corrosion of metals in an oxygenated aqueous environment is an electrochemical phenomenon in which the metal dissolves and forms ions in solution (anodic reaction), leaving electrons that combine with oxygen to produce hydroxyl ions (cathodic reaction). In anaerobic environments, oxygen is replaced by hydrogen ions or water as cathodic reactants. Biocorrosion, microbial corrosion, or MIC may be defined as an electrochemical process where the participation of the microorganisms is able to initiate, facilitate, or accelerate the corrosion reaction without changing its electrochemical nature [8].

Bacteria can act as environmental catalysts to stimulate corrosion. Colonies that include several kinds of bacteria can form deposits on metal surfaces, build slime layers and produce organic acids that cause pitting and accelerate corrosion. Microbial induced corrosion involves the generation of biofilm strata where anaerobic conditions exist (e.g. behind bentonite grout or within a thick accumulation of biomass). This biofilm leads to the generation of corrosive hydrogen sulfide (electrolytic solution) and/or organic acids. Microbial induced corrosion tends to be highly localized and characterized by elongated pits that tunnel into the specimen, often in an irregular manner.

There is a strategic need to retard this corrosion activity. One solution includes the implementation of a galvanic protection system for the MW stainless steel casing if economically feasible. A galvanic protection system will not reverse existing corrosion problems but will reduce the rate of future electrochemical corrosion significantly.

The results from corrosion studies [1,9,10] indicate that corrosion in MWs at PGDP is primarily caused by electrochemical phenomena (galvanic electrolysis) and enhanced by MIC, in this case SRB. The galvanic activity is localized between the stainless steel well casing (anode) and the iron isolation casing (cathode). To a lesser degree SRB are also attacking the well casing exterior below the isolation casing, usually along the weaker stainless steel weld seams. The use of polyvinyl chloride well casing in new wells, unless in a known volatile organic compound source area, will prevent future corrosion problems.

MONITORING WELL MAINTENANCE SCHEDULE

The PGDP MW network consists of approximately 239 wells which support a variety of environmental monitoring programs. Of these 239 wells, 69 MWs are compliance wells supporting regulatory-driven programs. Seventy-four MWs are surveillance wells supporting programs driven by Department of Energy orders. Seventy-five wells (MWs and piezometer) are used exclusively for water level measurements. Finally, 21 are residential wells. All these wells except the residential wells are included in the maintenance program to maintain the quality of samples taken to support environmental programs at the site.

Long-Term Maintenance Schedule

Funding is expected to be available to rehabilitate 30 MWs per year for the next several years. The compliance wells will be addressed first and rehabilitation will begin this calendar year (CY). These wells are known to be biofouled and in need of rehabilitation [2,4] and support compliance driven environmental monitoring programs. Each well will be rehabilitated using BCHT^{TM}.

Also, maintenance monitoring will be initiated on all wells. Maintenance monitoring, discussed in detail in Section 3, involves the collection of information (physicochemical parameters, visual observations, well performance) necessary to determine when maintenance is necessary. This information will be used to establish the annual maintenance schedule after all the compliance wells have been initially treated. This approach of aggressively treating known problem wells now, along with future prioritization based on maintenance monitoring, is illustrated by the schedule shown in Table I.

Table I. Long-Term Scheduling Approach

Year	Compliance wells	Surveillance wells	Water level wells	Total
2002	30			30
2003	30			30
2004	9	21		30
2005		30		30
2006		23	7	30
2007			34	34
2008			34	34
Total	69	74	75	218

Compliance Monitoring Wells

The 30 most severely biofouled compliance wells were selected to be rehabilitated first. The selection was based on the results of past video inspections and report findings [1,2] along with groundwater sampling logbook entries.

Surveillance Monitoring Wells

Unlike the compliance wells, very few surveillance wells have been inspected using a video camera. Consequently, on an annual basis, maintenance monitoring data suggestive of biofouling (e.g., oxidation-reduction potential, pH, conductivity, Fe, Mn, and S concentrations) along with other factors (e.g., the well's strategic location and visual sample examination and pump condition) will be used to select wells requiring maintenance.

Compliance Monitoring Wells

There are limited analytical data available for wells used primarily for water level measurements. Scheduling will be based on the strategic location of each well and a review of the water level data from a well. Microbial plugging may be inferred by anomalous water level measurements.

MAINTENANCE MONITORING

Maintenance monitoring involves the collection and evaluation of physical, hydraulic, and water quality factors for the purpose of detecting deteriorating conditions in the well. Maintenance monitoring helps identify problems early so that preventive maintenance can be scheduled. Repair and replacement intervals and preventive maintenance treatments can then be chosen and fine-tuned accordingly. The maintenance monitoring program involves visual inspection of downhole equipment, downhole video inspection, evaluation of physicochemical water quality data, microbial sampling and analysis, and assessing well performance indicators. The maintenance monitoring activities are summarized in Table II and discussed in more detail below. A brief annual report, reporting the results of maintenance monitoring and identifying wells recommended for treatment, will be developed.

Table II. Maintenance Monitoring Summary

Wells	Maintenance monitoring				
	Visual inspection	**Physicochemical water quality**	**Video inspection**	**BART™**	**Well performance**
Compliance	X	X	X	X	X
Surveillance	X	X			X
Water Level	X	X			X

Visual inspection – during normal sampling events
Well performance – during normal sampling events
Physicochemical – annual trend and analysis
Video Inspection – after initial BCHT™ rehabilitation only
Biological Activity Reaction Test™ – annually and with any BCHT™ application

Visual Inspection of Downhole Equipment

When pumps and discharge lines are pulled (such as for routine repairs) they will be inspected for signs of corrosion, biofouling, and encrustation. Equipment showing evidence of these will be photographed and observations noted in field logbooks. All equipment will be refurbished and rebuilt if necessary.

Video Inspection

Inspection with a downhole video camera is not a routine part of maintenance monitoring but may be conducted at the request of the Department of Energy. When properly used, downhole video provides a direct view of conditions within wells. Video documents the as-built condition and timing of subsequent well damage and deterioration. A progression of videos in any particular well, especially from the original construction condition, provides a direct way to watch changing conditions in the well (e.g., progressing screen corrosion of biofouling development). Each compliance well, following rehabilitation, during CY 2002 through CY 2004 will be inspected with a downhole camera to document the conditions of the screens and casings to compare to pre-treatment conditions.

Physicochemical Water Quality

The purpose of physicochemical monitoring is to detect changes in parameters that may reflect well deterioration or indicate the cause of well deterioration. The objective is to detect change over time and early enough to make maintenance decisions. Fluctuations in physicochemical parameters, such as increases or decreases in Eh, pH, conductivity, Fe, Mn, and S concentrations, are indicative of the well environment [7]. Redox potential is very important to the make-up of the microflora in the well and aquifer and also to the fate of Fe, Mn, and S, which produce mineral forms of precipitates. Parameters relevant to formation of encrustations (e.g., Ca^{2+} ion) will be evaluated. Total organic carbon content will be evaluated because it is an empirical indicator of biofouling potential. Particle counting and turbidity are significant site-specific parameters denoting the origin of minerals and/or precipitates. Increases in turbidity and particle counts indicate suspended solids content that may result from silting or biofouling [7]. Such solids data are useful in specifying remedial treatments (e.g., if only silt is present, the well may simply require redevelopment). Table III is a summary of physicochemical parameters relevant in well maintenance [7].

Table III. Summary of Physicochemical Parameters Relevant to Well Maintenance

Parameter	Diagnosis
Fe (total, Fe^{2+}/Fe^{3+}, minerals, and complexes)	Indications of clogging potential, presence of biofouling, Eh shifts
Mn (total, Mn^{2+}/Mn^{4+}, Mn minerals and complexes)	Indications of clogging potential, presence of biofouling, Eh shifts
S (total, S^{2-}/S^{0}/SO^{2-}, S minerals and complexes)	Indications of clogging potential, presence of biofouling, Eh shifts
Eh (redox potential)	Direct indication of probable metallic ion states, microbial activity. Usually bulk Eh, which is a composite of microenvironments
pH	Indication of acidity/basicity and likelihood of corrosion and/or mineral encrustation. Combined with Eh to determine likely metallic mineral states present, and with conductivity and alkalinity to assess inorganic salts occurrence
Conductivity	Indication of total solids content and a component of corrosivity assessment
Turbidity	Indication of suspended particles content, suitable for assessment of relative changes indicating changes in particle pumping or biofouling
Particle counts	Indication of suspended particles content, suitable for assessment of relative changes indicating changes in particle pumping and biofouling
Salt/silt content (v/v, w/v)	Indication of success of development/redevelopment, potential of abrasion and clogging
Total organic carbon	Empirical indicator of the potential for biofouling

Source: [7]

Analytical data assessment reports are currently being reviewed on all landfill compliance wells under various schedules. The assessment reviews should also evaluate any noticeable changes relating to biofouling monitoring.

Performing an annual review on surveillance MWs analytical data relative to key physicochemical changes is necessary in the overall preventive maintenance program.

Microbiological Sampling and Analysis

Currently, the most practical and promising cultural approach to detect nonfilamentous, metabolically active biofouling microflora in water wells is the Biological Activity Reaction Test (BART™) method. The BART™ test kits are inexpensive, are relatively easy to use, and are increasingly accepted as the standard biofouling monitoring method in the water well industry. Recently, BART™ results were shown to be very effective in assessing the success of rehabilitation efforts in Extraction Well (EW)-331 and EW-332 at the Northeast Plume Containment System (5).

BART™ testing will be conducted annually in compliance wells beginning one year following well rehabilitation. Increases in microbial activity will be evaluated to determine the need for treatment.

Well Performance

During routine well sampling activities, factors relating to well performance are logged in field notebooks. These factors will be evaluated along with other information to determine the need for maintenance. Table IV summarizes a variety of well performance problems and causes.

Table IV. Causes of Poor Well Performance

Performance problems	Possible cause
Sand/Silt Pumping	Inadequate screen and filter-pack selection or installation, incomplete development, screen corrosion, collapse of filter pack due to excessive vertical velocity and washout. Rock wells: presence of sand or silt in fractures intercepted by well-completed open hole, incomplete casing bottom seat. Causes pump and equipment wear and plugging
Silt/Clay Infiltration	Generally inadequate seal around the well casing or casing bottom, infiltration through filter pack, or "mud seams" in rock, inadequate development, or overdevelopment in tills. Or material so fine that formation cannot be monitored without accepting some turbidity. Causes reduced performance, filter plugging and interference with samples
Pumping Water Level Decline	Outside influences such as area or regional water level declines or well interference, or plugging or incrustation of the bore hole, screen, or gravel pack. Sometimes a regional decline will be exaggerated at a well due to plugging
Lower (or Insufficient) Yield	Dewatering or caving in of a major fracture or other water-bearing zone, pump wear or malfunction, incrustation, plugging, or corrosion and perforation of column pipe, increased total dynamic head in water delivery or treatment system
Complete Loss of Production	Most typically pump failure (mechanical or electrical), but also possibly catastrophic loss of well production due to dewatering, plugging and collapse
Chemical Incrustation	Deposition of saturated dissolved solids, usually high calcium, magnesium, carbonate and sulfate salts or iron oxides. Causes reduced specific capacity and well efficiency, interference with sample analyses. Actually rare except for deep wells in highly mineralized groundwater, as in the U.S. West

Table V. Causes of Poor Well Performance (Cont.)

Performance problems	Possible cause
Biofouling Plugging	Microbial oxidation and precipitation of Fe, Mn, and S with associated growth and slime production. Often associated with simultaneous chemical incrustation and corrosion. Associated problem: well "filter effect": samples and pumped water are not necessarily representative of the aquifer. Usually includes "iron bacteria." Causes reduced specific capacity and efficiency, reduced yield, interference with sample quality, and even complete well production loss. Often works simultaneously with other problems such as silting
Pump/Well Corrosion	Natural aggressive water quality, including hydrogen sulfide, sodium chloride-type waters, biofouling and electrolysis due to stray currents. Aggravated by poor material selection in pump or column pipe, casing and screen. May result in secondary system symptoms
Well Structural Failure	Tectonic ground shifting, ground subsidence, failure of unsupported casing in caves or due to poor grout support, casing or screen corrosion and collapse, casing insufficient for in-ground conditions, local site operations, collapse of unstable rock bore hole

Source: [7]

Historical Data

Historical data are indispensable in a preventive maintenance program. Time series plots revealing parameter changes in analytical data (Table III) along with visual examinations of sample characteristics (e.g., floating slime, etc.) are useful in analyzing current or potential bore hole conditions. Prioritizing MWs for maintenance is subjective. However, a review of the historical data should reveal severe problems. The historical data, when combined with physicochemical monitoring, is the best approach to prioritization for any CY.

CHEMICAL AND MECHANICAL TREATMENT

Biofouling has been shown to be a common problem threatening MWs at PGDP. To control biofouling and maintain sample quality and integrity, BCHT™ will be applied to 30 MWs each year. Depending on the severity of fouling and results from the maintenance monitoring program, BCHT™ will be applied as either preventive maintenance or full rehabilitation.

BCHT™ applied as preventive maintenance differs from full rehabilitation. Preventive maintenance is applied before major problems (e.g., microbial plugging, fouling) arise. Consequently, the objective is simply to apply the heated chemicals, allow them to set 24 hours and then remove them. Unlike full rehabilitation, aggressive mechanical methods are not required to remove biomass, sediments, etc. Consequently, preventive maintenance is much shorter and quicker.

Full rehabilitation is conducted after severe biofouling and/or microbial plugging have occurred. This method combines conventional mechanical treatments (brushing, jetting, surging, and airlift pumping) with BCHT™ application. Although specific chemicals are recommended in this plan, chemical selection may be slightly modified based on the observed effectiveness of the chemicals during rehabilitation, and practical considerations relating to their application. It is anticipated that the total time for rehabilitating each well is four days. The rehabilitation time may increase if operational, effectiveness, or compatibility problems arise. Preventive maintenance applications are anticipated to take approximately one to two days.

The following sections describe the BCHT™ process, as it will be applied for full rehabilitation on the compliance wells. Full rehabilitation will be applied on wells when microbial plugging and encrustation is known to exist within the well screen. Future preventive maintenance applications will consist of the shock phase along with any appropriate mechanical processes as determined from maintenance monitoring.

Pump Removal

This first step involves removing the pump and associated discharge line (piping) and inspecting for evidence of biofouling, corrosion, and mechanical failure. Equipment showing evidence of these will be photographed. All pumps will be refurbished and rebuilt if necessary before reinstalling.

Brushing Of Well

Following removal of the pump and pump column, the well will be brushed to remove any biofilm, scale, or encrustation. A snug-fitting brush will be used to brush up and down the length of the well. As the well casing is brushed, the biofilm along with any scale and encrustation will be allowed to settle to the bottom of the well. Following completion of brushing the well, the debris will be removed as necessary.

BCHT™

The next step involves applying BCHT™ to begin cleaning the filter pack and formation surrounding the well.

Chemical Mixture

Based on the available information, the compliance wells to be addressed first are biofouled and possibly mechanically plugged. The mechanical plugging most likely results from incomplete development. A mixture of hydroxyacetic acid (70%), sulfamic acid (99.5%), and CB-4 (ARCCSPERSE CB-4), a wetting agent, will be used to address the biofouling. Additionally, a non-phosphate mud dispersant (AQUA-CLEAR™ PFD) will be added to address the mechanical blockage. The chemicals will be mixed with water in proportions of 450 gallons of water, 25 gallons of hydroxyacetic acid, 50 pounds sulfamic acid, 5 gal CB-4, and 5 gal non-phosphate mud dispersant. This mixture was shown to be highly effective in treating biofouled wells at the PGDP. Approximately 150 gal of the mixture will be injected into each 10-ft length of screen. The mixture may vary depending on entry pressures and monitoring results.

Care will be taken to follow all federal, state and local regulations pertaining to the handling of treatment chemicals. Volumes of all chemicals injected will be recorded. It is anticipated that most chemicals will be recovered during subsequent redevelopment. Table VI summarizes the injection chemicals and their breakdown products or byproducts.

Table VI. Injection Chemicals Breakdown Products or Byproducts

Injection chemical	Breakdown product or byproducts
Sulfamic acid	Ammonium bisulfate and ammonium sulfate, and various salts resulting from materials with which the acid comes in contact and reacts
Hydroxyacetic acid (glycolic acid)	Sodium hydroxide and chloroacetic acid
ARCCSPERSE CB-4	Phosphines, carbon monoxide, carbon dioxide, and oxides of nitrogen
Aminotri (methylene- phosphonic acid)	
Ethylenediaminetetraacetic acid (EDTA)	Sodium cyanide and formaldehyde are ingredients, but are not expected in the residuals or in breakdown products. Information on breakdown is not available. EDTA is stable under normal conditions, and is not expected to bioaccumulate, nor is it toxic to aquatic life.
Polyacrylate	Copolymers of acrylic acid
AQUA-CLEAR™ PFD (Polyelectrolyte)	Carbon dioxide and carbon monoxide

Rehabilitation Phases

The BCHT™ method consists of three phases designed to remove the accumulated biofilm and blocking materials from the well screen, well bore, and surrounding aquifer. Table VII lists and briefly describes these phases [11].

Table VII. Three Phase BCHT™ Process

Phase	Description	Expected duration (days)
Shock	Heated chemicals are jetted into the screen and allowed to sit overnight	1
Disrupt	Continue to vigorously apply heated chemicals via jetting	1
Remove	Redevelop the well using surging and airlift pumping techniques	2

Shock Phase

In the shock phase, the chemical mixture is heated and applied with the aid of a jetting tool to maximize impact and penetration. The heated chemicals (approximately 200 degrees Fahrenheit) are jetted into the formation at approximately 600 pounds per square inch. The initial line speed for the jetting tool will be approximately 1 foot per second. This also can be increased as the screen begins to clear. The objective is to establish turbulence and a surging effect in the borehole to improve chemical entry into the plugged zones. Along with radial movement from the well bore into the formation, the interaction of hot and cold water creates a convection process establishing a secondary upward motion. As the heat reacts with the cold water, the convection process moves upward and outward with the pinnacle moving out into the formation achieving deeper penetration than non-heated methods.

Disrupt Phase

The disruption phase follows the shock phase after the well has set overnight. The same mechanical procedure is performed during this phase. The objective is to apply heat and chemicals to the well screen and as far out into the formation as possible. Disruption is aided by radically lowering the pH to <2 (a minimum pH of 3 is required during the disruption phase). During the disruption phase the biomass structures begin to collapse. As this collapse continues, the biomass fragments into particles that can be pumped from the well. The effectiveness will be monitored qualitatively by the visual inspection of the material removed. This is performed by monitoring the color and solids content of water collected periodically during redevelopment.

Remove Phase

The objective of this phase is to remove the fragmented biomass and blocking materials contributing to well plugging. Removing the biomass from the well and surrounding aquifer prevents it from becoming the feedstock for subsequent buildup. This phase is essentially a redevelopment of the well and consists of repetitive surging and airlift pumping. Based on lessons learned during recent rehabilitation efforts at EW-331 and EW-332 [5,6], an airlift surge block will be used during this phase to produce simultaneous surging and pumping within the well. Additionally, a separate staging tank located between the extraction wells and water storage tanks, will be used to temporarily store water generated during airlift pumping.

During the shock and disrupt phases of the treatment process, approximately 300 gal of the treatment blend will be injected into each well. Removal of the injection chemicals will be measured by comparing the pH of the development water to the average pH value for the well.

WASTE MANAGEMENT

This section addresses the management of wastes generated during the implementation of well maintenance from the point of generation through characterization and disposition. Standard practices and procedures outlined in this section regarding the handling, transportation, and storage of wastes will comply with all Resource Conservation and Recovery Act (RCRA) and Toxic Substances Control Act (TSCA) requirements should polychlorinated biphenyls become an issue. Additional PGDP and Department of Energy waste management guidelines have also been incorporated.

Requirements specific to PGDP include proper containerization of all wastes as required by RCRA/TSCA, transportation of the wastes to the appropriate storage area, characterization of the waste, and radiological screening of environmental and waste characterization samples before shipment off-site. The approach outlined emphasizes the following objectives:

- Manage the wastes in a manner that is protective of human health and the environment;
- Minimize the waste generation, thereby reducing unnecessary costs and usage of permitted storage and disposal facilities, which are limited in number;
- Comply with federal and state requirements;
- Select management options consistent with the final remedy selected for the site from which the waste was generated; and
- Initiate a study to dispose of development water at the Paducah site in a more economical and logistical manner. (Suspended fines in development water have been a challenge for several years).

Types of Waste

A variety of potentially contaminated and uncontaminated wastes will be generated. All waste generated as a result of field activities have the potential to contain contaminants related to known or suspected past disposal practices, primarily trichloroethene (TCE), and technetium-99 (^{99}Tc). Waste types expected to be generated during well maintenance activities include solid wastes (primarily plastic and personal protective equipment (PPE) and wastewater composed of equipment decontamination water and well rehabilitation/development water.

Solid Waste

Solid waste, consisting primarily of plastic and PPE, will be generated during field activities associated with these activities. This waste will be properly containerized and labeled in accordance with applicable requirements and temporarily stored pending characterization. Characterization of this waste (as mixed waste) will be based on the results of periodic radiological surveys of individual work sites performed. Based on the results of the radiological surveys this waste stream will be transferred to interim storage and ultimate disposal at an alternate facility. It is estimated that two 55-gal drums of solid waste will be generated each year assuming 30 wells are treated.

Wastewater

Wastewater composed of well rehabilitation/development water and decontamination water from the cleaning of field equipment and sampling equipment will be generated.

Wastewater generated will be properly transported to a treatment facility, and filtered and treated prior to release at a permitted outfall. Prior to initial sampling, decontamination water will be kept separate from rehabilitation/development water. The pH of all rehabilitation/development water will be adjusted to a range of between 6.0 and 9.0 by the addition of an approved buffering agent (e.g., soda ash).

It is estimated that approximately 1200 gal per well will be generated. If the water is filtered separately from the treatment system, then filter cake may be generated. The volume is dependent on the process but history has shown that approximately 1 drum per well of filter cake is generated.

RESULTS

Eighty MWs underwent treatment with the BCHT™ process from September 2003 to January 2004. The project was completed with one rig called a “Stinger” (Fig 1). Figs 2 and 3 represent the condition of many of the well interior components prior to rehabilitation.

pH readings were collected during the redevelopment of the MWs to identify when all the chemicals had been removed from the MW. The readings were compared to data collected prior to treatment to ensure that the well was brought back to original environmental conditions.

Upon completion of each well, a video inspection was performed to ensure that the cleaning process was adequate. If any well appeared to be deficient at that time, further recommendations were made regarding abandonment and future use. Overall, the video inspection for each well after the treatment process showed a marked improvement in the “cleanliness” of the well. The subsequent samples collected were of better quality from a visual and an odor standpoint. It was observed that the age of the well did not directly contribute to the conditions identified. It appears that the surrounding conditions of the soil have a more significant influential factor in the well performance.

Fig. 1. MW rehabilitation "Stinger" rig

Fig. 2. MW300 tubing and screen

Fig. 3. MW197 pipe and screen

CONCLUSIONS

Since this project, some wells have already exhibited "dirty" samples. Some of these are more recently installed wells, but are installed in the more problematic soils that we have seen at the site. These soils are related to the corrosive conditions identified. Future actions will consider these factors. Some of the wells should be put on a more frequent program, while others may not need rehabilitation for 5-10 years.

This process proved to be very effective for cleaning the MWs. Data quality is improved since the process was implemented. The program should be re-evaluated to determine routine frequency for future rehabilitation campaigns.

REFERENCES

1. Bechtel Jacobs Company LLC 2000a. *C-746-S&T and C-746-U Landfills Monitoring Wells Camera Inspection*, Paducah, Kentucky, BJC/AD-186, May, 2000.

2. Bechtel Jacobs Company LLC 2000b. *C-746-K Landfill, C-404 Burial Ground, Northeast Plume Monitoring Wells, and Northwest Monitoring Wells, (North and South Fields) Camera Inspections at the Paducah Gaseous Diffusion Plant,* Paducah, Kentucky, BJC/PAD-204, August, 2000.

3. Bechtel Jacobs Company LLC 2001. *Results of the Monitoring Well Corrosion Study, Paducah Gaseous Diffusion Plan,* Paducah, Kentucky, BJC/PAD-239.

4. Bechtel Jacobs Company LLC 2000c. *Well Rehabilitation Plan for Extraction Wells EW-331 and EW-332 at the Paducah Gaseous Diffusion Plant,* Paducah, Kentucky, July 2000.

5. CDM 2002a. *Draft Well Rehabilitation Plan for Extraction Wells EW-230 and EW-231, Paducah Gaseous Diffusion Plant,* Paducah, Kentucky, January 2002.

6. CDM 2002b. *Draft Well Rehabilitation Completion Report for Extraction Wells EW-331 and EW-332, Paducah Gaseous Diffusion Plant,* Paducah, Kentucky.

7. Smith 1995. Smith, S.A., 1995. *Monitoring and Remediation Wells: Problem Prevention, Maintenance, and Rehabilitation,* CRC Press, 1995.

8. Videla, 1996. Videla Hector, Manual of BIOCORROSION, CRC Press, 1996.

9. Underwood, Dan 2000a. Materials and Chemical Technology, United States Enrichment Corporation, Letter to Stan Knaus, Lan-Con, Inc., March 24, 2000.

10. Underwood, Dan 2000b. Materials and Chemical Technology, United States Enrichment Corporation. Letter entitled Evaluation of Piping Northeast Plume, February 21, 2000.

11. Alford and Cullimore 1999. Alford, G and D. R. Cullimore, *The Applications of Heat and Chemicals in the Control of Biofouling Events in Wells,* Sustainable Water Well Series, D.R. Cullimore Series ed., CRC Press, 1999.