**IN SITU TREATMENT OF SOILS CONTAMINATED
WITH MANUFACTURED GAS PLANT WASTES,
DEMONSTRATION PROGRAM**

Final Report

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EXECUTIVE SUMMARY

By adapting secondary and heavy oil recovery technology, Western Research Institute (WRI) developed the contained recovery of oily waste (CROW™) process, which removes organic contaminants from the subsurface. The technology was successfully tested in the laboratory as part of a project for the U.S. Environmental Protection Agency (EPA) SITE Program's Emerging Technology Program. The EPA advanced the CROW process to the SITE Demonstration Program based on the laboratory results. Additional development of the process included a pilot test at an active wood treatment facility. The purpose of this project was to demonstrate and evaluate the effectiveness of the CROW process for remediation of a site contaminated primarily with a dense organic waste. The site selected for this demonstration project was a former manufactured gas plant (MGP) located in Stroudsburg, Pennsylvania.

Because the selected site is a Superfund site, the procedures required for this project were established by the EPA. The project design process required the development of a detailed work plan followed by a sequential site design of three steps: (1) a 30% design for the field layout and operation; (2) a 95% design for the field layout and operation, with all equipment, well construction, and operating procedures fully specified; and (3) a final project design based on the review comments from the 95% design submission.

The initial progress of the project was slowed by additional requirements for recharacterization of the site as requested by the EPA. The project was also delayed by the required redesign and approval protocol and by weather and problems with personnel availability. During system shakedown, operational problems with control of the hot-water heater, with the integrity of the injection wells in the shallow, unconsolidated aquifer, and with the treatment system caused by production of dissolved iron from the aquifer all resulted in further delays. With time, all of the problems were corrected, or operational changes were made to minimize the impact of the problems.

During the 231-day shakedown period, 7.3×10^6 gal of fluid were produced from the pattern area and 5.4×10^6 gal of ambient temperature water were reinjected. Of the produced fluid, 1.9×10^6 gal were treated by the biological reactor system and disposed to Brodhead Creek. During the subsequent 336 days of hot-water injection, 9.5×10^6 gal of water were injected and 11.6×10^6 gal of fluid were produced, with 2.1×10^6 gal of produced water treated and disposed of. The average pattern injection and extraction rates for the hot-water injection period were 19.6 and 25.5 gpm, respectively. During the operation of the system, 1504 gal of coal tar were produced.

INTRODUCTION

The contained recovery of oily waste (CROWTM) process developed by Western Research Institute (WRI) removes organic contaminants from the subsurface by means of adaptation of technology used for secondary and heavy oil recovery. The CROW technology was successfully tested in the laboratory as part of a project for the U.S. Environmental Protection Agency (EPA) SITE Program's Emerging Technology Program (Johnson and Guffey 1990). The experimental program consisted of several one- and three-dimensional hot-water flushing tests to simulate the process. The tests were conducted with organically saturated, sand packed tubes and blocks. These experiments showed that hot-water flushing could reduce the organic contaminant content by approximately 60%. Further testing with totally biodegradable chemicals showed that the removal rate could be increased to approximately 90%. Additional testing showed that the CROW process did not hinder but helped in the biodegradation of the residual organics (Johnson and Leuschner 1992). Based on the laboratory performance of the process, the EPA advanced the process to the SITE Demonstration Program.

Further development of the process has included the completion of a pilot test at an active wood treatment facility. The pilot test provided additional information for the design of a field-scale remediation effort in addition to verifying several of the prepilot design specifications and predictions. Verified by the pilot test were the abilities to: (1) establish and maintain desired injection and extraction rates, (2) heat the test area to the desired temperature, (3) achieve non-aqueous phase liquid (NAPL) removal rates equivalent to laboratory rates, and (4) show that the produced fluid can be treated for reinjection or disposal (Fahy et al. 1992).

PURPOSE

The purpose of this project was to demonstrate and evaluate the effectiveness of the CROW process to remediate a site contaminated with dense organic waste. The effectiveness was measured by attaining in the field, treatment levels as stipulated by the EPA that were comparable to the laboratory results obtained during the SITE Program's Emerging Technology Program experiments.

BACKGROUND

The site selected for this demonstration project was the Brodhead Creek Superfund site in Stroudsburg, Pennsylvania, owned by Pennsylvania Power and Light (PP&L). For approximately 60 years prior to the mid 1940s, a manufactured gas plant (MGP) using a coal gasification process was operated at the site. From the mid 1940s until 1980, the site was abandoned. In 1980, during the repair of a flood control levee at the site, coal tar contamination was identified in the construction

cuts. In 1982, the site was placed on the National Priorities List. Feasibility studies conducted in the late 1980s and early 1990s resulted in the selection of the CROW process as a remediation alternative in the 1991 Interim Record of Decision.

The contamination at the site was in the uppermost geologic interval, a loosely consolidated to unconsolidated aquifer consisting of rounded boulders, cobbles, and gravel with varying amounts of sand. This unit overlies a fine-grained sand and silt layer that acts as an aquitard. The contaminated interval runs from the surface to a depth of approximately 35 feet in the process area, with the free coal tar contamination being concentrated in a depression near the center of the CROW Pattern area, Figure 1. The top of the water table ranges from 3 to 15 feet below ground surface in the process area and has an extremely high hydraulic conductivity equivalent to 100 to 150 Darcies. The movement of groundwater and coal tar has been in a southeastern direction across the CROW process pattern area.

During the 1980s, PP&L installed a pumping system in the immediate area of the CROW demonstration that resulted in the recovery of 8,000 gallons of pure coal tar (Villaume 1983). During a supplemental site investigation in 1993, an attempt was made to quantify the volume of free coal tar remaining within the target area. While a significant amount of tar contamination was encountered, it was not apparent that a free, continuous tar pool existed in this subsurface stratigraphic depression. Due to the heterogeneity of the subsurface sampling results, no adequate tar volume was quantified, although it was estimated at several thousand gallons (RETEC 1996). Because of the inability to accurately estimate the initial coal tar-in-place, it was impossible to determine the coal tar percentage recovery, which was needed for comparing the laboratory results with the field results.

The development of the operational parameters for the project were based on the laboratory physical simulations of the process conducted for the EPA SITE Program's Emerging Technology Program. The EPA established as a treatability goal for the project the removal of contaminants to a level equivalent to that in the laboratory testing. The measure of attaining this goal would be an increase in the cumulative organic recovery of less than 0.5% per pore volume of injected water, Figure 2, and the raising of the temperature in the treatment area to between 150 and 160°F.

The funding for the project was provided by the U.S. Department of Energy (DOE), the Gas Research Institute, PP&L, and the Electric Power Research Institute. WRI, in conjunction with Remediation Technologies Inc. (RETEC), was responsible for the design, construction, and operation of the project. Other participants working at the site included Atlantic Environmental Services Inc. (site characterization); Michigan Biotechnical Institute, now EFX Systems Inc. (water treatment for disposal); and the U.S. EPA SITE Demonstration Program (process monitoring, analysis, and evaluation).

LEGEND

- ◆ IW #2 Injection Well
- ◆ PW #1 Production Well
- ◆ EM-1 Monitor Well
- POLE
- JUNCTION BOX
- CHAIN LINK FENCE
- CONSTRUCTION FENCE

Figure 1. Brodhead Creek Site Layout, From RETEC

Figure 2. Laboratory Cumulative Organic Recovery Curve

METHODOLOGY

The procedures followed for this project were required by the EPA for remediation projects at hazardous waste sites. The CROW process could be used at this site because enhanced remediation techniques were identified and approved as potential methods in the Record of Decisions for the site. The first task was to develop and submit for approval a detailed work plan. The work plan identified all construction and environmental permits and showed that the project design would be completed in a sequence of three steps: (1) prepare and submit for approval a 30% design for the field layout and operation; (2) subsequent to initial approval, prepare and submit a 95% design for the field layout and operation, with all equipment, well construction, and operating routines fully specified; and (3) prepare a final project design based on the review comments from the 95% design submission.

Following approval of the project design, all equipment installation and construction of the field facilities would be followed by the actual operation of the field demonstration. Upon completion of the field demonstration, the field facility would be dismantled and the data analyzed. Report of the results would be made to the DOE, PP&L, EPA, and other cosponsors.

RESULTS AND DISCUSSION

The work plan for the field demonstration was submitted to and approved by the EPA Region 3 office. Following approval, the three-step system design and approval sequence was initiated and completed. The Pennsylvania Department of Environmental Protection (PADEP) was also included in the review of the design and operational requirements of the project. Also, all the environmental and construction permits required for the project were identified and obtained.

Initial System

The field facility consisted of the pattern area, a water injection system, a fluid production and separation system, a water treatment system, and a data acquisition and control system (DACS). The pattern area consisted of two interconnected, inverted five-spot patterns for a total of two extraction wells and six injection wells, as shown in Figure 3. Three wells, RCC, RCNE, and RCNW, had been pumped by PP&L during the 1980s. Many exploration wells had been drilled in the pattern area in an attempt to define the extent of the contamination. Eight of these exploration wells were initially used as temperature and groundwater level monitoring wells.

The water injection system consisted of the six injection wells and a hot-water heater. The six injection wells were completed by screening and gravel packing the casing through the bottom three-quarters of the water table and then sealing the annulus above the screen with 1 ft of bentonite pellets and finally completing the well to the surface with cement. Injected water was pumped from the recycle-water storage tank through a hot-water heater and distributed by a manifold to individual injection wells. The hot-water heater was a single-pass, 2000-watt electrical unit with four heater-element bundles.

The production system components consisted of the two extraction wells and the separation and storage tankage. The extraction wells were screened throughout the water table and contained two submersible pumps per well. In each well one pump was placed at the bottom of the well and the other pump was placed 2 to 3 ft below the top of the aquifer. The lower pump was the main extraction pump with the upper pump used to remove any light organics displaced to the well. The pumps were controlled by a series of level controllers and conductivity meters in the wells and the production tanks.

The production tankage consisted of four 20,000-gal and one 10,000-gal tanks. All extracted fluids first entered one or both of the first two 20,000-gal tanks through a spreader. Most of the heavy organics separated in these first two tanks, with the remaining fluid flowing overhead to a third 20,000-gal skimmer tank with a floating skimmer unit. Additional heavy organics settled to the bottom of the skimmer tank, while light organics rose to the top for removal by the skimmer unit.

Figure 3. Brodhead Creek CROW Test Pattern Layout

Water was removed from the skimmer tank at a point 6 ft from the bottom and pumped to a 20,000-gal recycle-water storage tank. The heavy organics from the bottom of the first three tanks and the light organics from the top of the skimmer tank were pumped to the 10,000-gal organic storage tank. Provisions were made for acid or sodium hydroxide injection into the production piping to regulate the fluid pH. This regulating of the produced fluid pH was to assist in the separation of the organics and the regulation of calcium precipitation.

Water treated for disposal was pumped from the recycle-water storage tank to the granular activated carbon fluidized bed reactor (GAC-FBR). The reactor used a biological process in which the organic-degrading organisms were grown on the granular activated carbon (Gruber 1996). The design, construction, and operational procedures for the GAC-FBR were provided by EFX Systems Inc.

The data acquisition and control system was PC-based and operated with LabTech Control software. The system gathered data from flowmeters in all production and injection lines; thermocouples in all wells and production tanks; level sensors in extraction wells and production tanks; and conductivity meters in selected tanks, lines, and in the extraction wells. All data were collected and displayed every 10 seconds and stored every 5 minutes to computer files, which were routinely downloaded via the modem system for analyses and archiving. From the recorded data, the control system determined what control should be exerted on the process. If required, the system would turn a pump, valve, or alarm on or off as specified by the control logic.

System Problems and Modifications

Shortly after initiating cold-water injection during system shakedown, a problem establishing satisfactory injection rates was noted for wells IW3, IW4, and IW5. The problem with IW4 and IW5 was the lack of competent overburden to establish a good seal around the well, which prevented the use of injection pressures necessary for satisfactory injection rates. The surface in the area of these two wells was approximately 3 ft above the water table and was the same boulder/cobble/gravel material as the aquifer. In an attempt to correct this problem, both wells were redeveloped to remove any debris from inside the screens, then a thermal packer was installed to restrict injection into the bottom 10 ft of the well. The redevelopment consisted of surging large volumes of water within the casing and screen to free any residual drill cuttings or other material that would restrict flow through the screens. This effort provided little, if any, improvement in the injection rates. Injection rates greater than 1 to 2 gpm were never achieved for these wells.

The problem with the injection into IW3 was caused by the proximity of the well to the levee wall. It appeared that the well was completed in the fringe area of the bentonite core of the levee. This bentonite-contaminated material restricted communication with the other pattern wells. Redevelopment to clean out residual debris did not improve the well performance. For all practical purposes, this well was nonfunctional as a pattern well. Because of the above described injection well completion problems, almost all water injection was limited to wells IW1, IW2, and IW6.

A further problem was the continual decrease in the injection rates for wells IW1, IW2, and IW6. Analysis of the reddish-white slime that was clogging the well screens and strainers and fouling

the turbine flowmeters in the injection system indicated a high iron content in the produced fluids, caused primarily by the iron in the aquifer. To minimize the problem, the water production and treatment system was modified to remove the iron, and the injection system and wells were cleaned.

The first two production tanks were repiped so that all production went first to tank 1 then from the top of tank 1 to the lower third of tank 2. Chemical injection systems were added to allow for pH adjustment of the produced fluids. The pH of the produced fluid was reduced to 5 prior to being pumped to tank 1. The pH was reduced with 93% sulfuric acid to improve separation of the organics from the produced fluid in tank 1. The water overflowed from tank 1 to tank 2, where the pH was increased to the 7 to 8 range with 35% sodium hydroxide prior to adding 50% hydrogen peroxide and a flocculent (polyacrylic acid) to precipitate the dissolved iron. The pH of the produced water recycled to the injection wells from tank 5 was then lowered to approximately 6 to prevent precipitation of iron in the heater and the wells when the water was heated. To further assist in the removal of any precipitate that passed the tank system, filters were installed before and after the hot-water heater. A sand filter and a bag filter were also installed prior to the carbon adsorption units. Figure 4 is the final as-built process flow diagram (Moeller et al. 1996).

The injection piping and wells required cleaning because of the iron precipitation problem. Cleaning consisted of flushing all piping to remove the sediments and the redevelopment of the wells to remove any deposition. To assist in keeping the wellbores clean, a jettering system was installed in all of the injection wells. The jettering system consisted of an air jet installed on a lance that penetrated to a location near the bottom of each injection well. Compressed air was then used to create a surging effect in the wellbore to clean the screen and to remove the displaced precipitates. When the system was operating, acid and/or chlorine could be added to assist in the cleanup. The modification of the treatment system and the well redevelopment helped the injection problem but did not totally eliminate it. As with IW4 and IW5, the lack of competent overburden ultimately restricted injection into wells IW1, IW2, and IW6. These combined problems limited the injection rates into these wells to about half of the desired rate of 17 gpm per well.

Establishing and maintaining the desired injection rate caused problems with the hot-water heater and the extraction wells. The hot-water heater was designed to heat 75 to 100 gpm of water from 50 to 200°F using an on/off control technique. Since the maximum injection rate was approximately 30 gpm, the control of the water temperature by the heater was impossible to modulate. To combat this problem, three of the four heater bundles in the heater were disconnected, and the fourth bundle was connected to a proportional controller. The heater operated more efficiently after this change.

Figure 4. Process Flow Diagram, As-Built, From Moeller, et al.

The extraction well problem stemmed from the sizing of the two extraction pumps at 60 gpm to supply 110 to 120 gpm of total recovery. Since the maximum injection rate was approximately one-third the planned rate, the extraction rate had to be reduced by one-third. This low extraction rate caused heat buildup in the pump, which accelerated wear on the pump motors and impellers. Repair and replacement of the downhole pumps became more frequent as the project progressed.

Other operational problems occurred with the biological treatment unit. Tuning the biological treatment unit took several months, and the carryover of some granular carbon and biological material from the fluid bed caused plugging of the pumps and carbon-adsorption drums in the discharge system. To prevent the plugging, strainers and micron-sized filters were installed before and after the fluidized bed. Organic fouling of the level indicators and particulate fouling of turbine flowmeters resulted in an extraordinary amount of cleaning, repair, and replacement of the instruments.

Also, software problems occurred with the DACS computer. Several attempts to reconfigure the system, the removal of unnecessary software, and routine rebooting of the system did not remedy the problem. The problem was finally corrected by installing Windows 95.0 and new versions of LabTech Control and Carbon Copy software. After installation of these new software packages, problems with the control system were essentially eliminated.

Other modifications to the operational system included removing the upper pumps from the extraction wells and installing these pumps in wells RCC and RCNE. This change was made because no noticeable floating organics were found in the extraction wells and there appeared to be small pools of organic material around RCC and RCNE. By pumping these two wells occasionally, the organic material that migrated to these monitor wells was removed. Also, the repiping of monitor wells for injection purposes was done in the area around IW4 and IW5 to increase the hot-water flow in that area.

Finally, while desired aquifer temperatures were typically achieved areally within a few days of initiating hot-water injection, it was difficult to heat the entire aquifer vertically. Consequently, the aquifer was usually hotter at the top than at the bottom. In an attempt to heat the entire aquifer, additional monitor wells spaced throughout the pattern were completed for injection. The final injection piping system is shown in Figure 5.

Figure 5. Brodhead Creek Final Pattern Piping Layout

CHRONOLOGY OF EVENTS

The following is a chronology of events associated with the remedial action at the Brodhead Creek Site:

<u>Date</u>	<u>Event</u>
March 1991	The EPA regional administrator signed the record of decision.
September 1992	The Consent Degree was entered in the U.S. District Court for the Eastern District of Pennsylvania.

<u>Date</u>	<u>Event</u>
January 1993	The Remedial Design Work Plan (RDWP) was submitted. The RDWP contained descriptions of all of the documents that were to be submitted as part of the remedial design.
April 1993	The 30% design was submitted.
July 1993	The 60% design was submitted.
January 1994	The prefinal design was submitted.
March 1994	The final design was approved. The final design contained a Work Plan, a Quality Assurance Project Plan, a Construction Quality Assurance Plan, a Field Sampling Plan, a Site Security Plan, a Contingency Plan, a Permitting Plan, a Biota and Sediments Monitoring Plan, a Health And Safety Plan, a Decontamination Plan, and an Operations and Maintenance Plan, plus blueprints, and construction specifications.
April 1994	Construction contractors were selected.
May 1994	Construction commenced.
July 1994	All production and injection wells were completed.
October 1994	Construction was completed.
December 1994	Operator training and debugging of preliminary operations were completed.
February 1995	The system was modified with an iron removal step and additional inline filtration.
July 1995	The system began operating with consistent high temperatures. The counting of pore volumes of water injected began.
January 1996	The last traces of recovered tar were transferred into the oil storage tank. This occurred at the fifteenth pore volume injected.
April 1996	The system was modified to provide higher aquifer temperatures for the final pore volumes injected and extracted.
June 1996	After oral approval from the EPA, the system was shut down because of the lack of tar in the production water.

RESULTS

Construction of the field facilities began in mid 1994 and was completed in the fall of 1994. Shakedown of the system using ambient temperature water began in November 1994 and continued through June 1995. Problems associated with the operation of the system were addressed during this shakedown period. Beginning in July 1995, hot-water injection was established and was nearly continuous until shutdown in June 1996.

During the 231-day shakedown period, 7.3×10^6 gal of fluid were produced from the pattern area and 5.4×10^6 gal of ambient temperature water were reinjected. Of the produced fluid, 1.9×10^6 gal were treated by the biological reactor system and disposed to Brodhead Creek (Table 1).

Table 1. Brodhead Creek Site Test Summary Through July 7, 1995

Cold Water Injection Time, days	231
Total Cold Water Injected, gallons	5,397,898
Total Cold Water Extracted, gallons	7,310,837
Total Water Disposed, gallons	1,912,939
Average Cold Water Pattern Injection Rate, gpm	16
Average Cold Water Pattern Extraction Rate, gpm	22
Average Water Disposal Rate, gpm	6

During the hot-water injection phase, 9.5×10^6 gal of water at an average heater outlet temperature of 147°F were injected. During the subsequent 336 days of hot-water injection, 11.6×10^6 gal of fluid were produced, with 2.1×10^6 gal treated and disposed of. The average pattern injection and extraction rates for the hot-water injection period were 19.6 and 25.5 gpm, respectively, as shown in Figure 6.

Figure 6. System Flow Rates for the Hot-Water Injection Period

Most of the extracted fluid was produced from PW2. During the operation, 60,600 additional gallons of fluid were also produced intermittently from RCC and RCNE. Operational conditions during the hot-water injection period are summarized in Table 2.

The excess water that was treated and disposed of was the result of deliberate overpumping of the extraction wells. A groundwater extraction rate exceeding the total water injection by approximately 4 gpm was maintained, which created a cone of depression around the pattern area and maximized containment of the injected water.

Steady-state areal temperatures were achieved in the aquifer after about two weeks of constant hot-water injection and extraction, as shown in Figure 7. Aquifer temperatures in the active extraction well, PW2, stabilized to approximately 130°F after about 50 days of continuous injection, as shown in Figure 8. Unfortunately, it was difficult to heat the bottom of the aquifer until some of the monitor wells were converted into injection wells, Figure 5. The additional injection improved the overall aquifer heating, and more uniform vertical heating profiles were achieved for a short period prior to the system shutdown. However, no additional coal tar was recovered by the modified injection scheme. The final aquifer temperatures in the immediate area of the extraction wells were in the range of 140 to 150°F.

Table 2. Brodhead Creek Site Test Summary, July 8, 1995–June 17, 1996

Hot Water Injection Time, days	336
Average Heater Outlet Temperature, °F	147
Total Hot Water Injected, gallons	9,467,136
Total Hot Water Extracted, gallons	11,610,864
Total Water Disposed, gallons (Includes RCC and RCNE)	2,204,352
Total RCC and RCNE Water Extracted, gallons	60,624
Total Hot Water Injected, pore vol (455,000 gal/PV)	20.8
Total Hot Water Extracted, pore vol (455,000 gal/PV)	25.5
Average Hot Water Pattern Injection Rate, gpm	19.6
Average Hot Water Pattern Extraction Rate, gpm	24.0
Average Water Disposal Rate, gpm	4.4
Average Well Flow Rates, gpm	
IW1	7.7
IW2	5.5
IW3	0.0
IW4	1-2
IW5	1-2
IW6	4.6
PW1	3.0
PW2	21.7
Total Organic Recovery, gal	1504

Figure 7. Brodhead Creek Temperature Contours Before Adding Additional Injection Wells

Figure 8. Brodhead Creek Extraction Well Temperature Profiles

Some aquifer heating outside of the immediate pattern area occurred, particularly in the areas of wells RCNE and RCNW. However, monitor wells D-1A and W-5, which were located down-gradient from the pattern, did not exhibit a significant temperature increase, suggesting good containment of the injected hot water throughout the operational time period. Aquifer groundwater contours also suggest containment was achieved, as shown in Figure 9. Aquifer drawdown in the vicinity of the extraction wells was on the order of one to two feet. The aquifer levels outside of the pattern area were unchanged throughout the operation of the process.

Figure 9. Brodhead Creek Aquifer Drawdown Contours

The unconfined nature of the CROW process pattern made it difficult to precisely determine the affected pore volume. A pore volume was estimated as the area in Figure 7 that was heated to 150°F, having a thickness of 20 feet and a porosity of 35%. A value of 455,000 gallons was subsequently assigned as the affected pore volume. The total hot-water injected and extracted pore volumes were therefore measured at 20.8 and 25.5, respectively.

During the operation of the system, 1504 gal of coal tar were produced, including approximately 80 gallons of coal tar removed by the GAC-FBR and the bag filters (Gerrish 1996). Most of the coal tar was produced during the hot-water injection phase; Figure 10 is a plot of organic production versus hot water injected. After injecting 15 pore volumes of hot water, the increase in the cumulative organic recovery was less than the goal of 0.5% per pore volume of injected water, indicating that essentially all producible organics were recovered. While the actual percentage of coal tar-in-place recovered could not be quantified, the recovery is believed to be similar to the laboratory recovery.

10. Brodhead Creek Cumulative Organic Recovery Curve

CONCLUSIONS

The progress of the project was initially slowed because of problems encountered in the recharacterization of the site, as requested by the EPA, and the length of time required and complexity of the EPA design and approval protocol. Weather and personnel availability caused further delays. The unconsolidated nature and shallowness of the aquifer caused problems in obtaining the desired injection rates, resulting in a longer period of operation to attain the desired system throughput.

The EPA remediation criteria for recovery of the organic contaminant were effectively met by the CROW process. Sufficient pore volumes were injected and extracted to ensure that no additional coal tar could have been recovered with the CROW process.

While the actual percentage of coal tar-in-place recovered could not be quantified, the recovery is believed to be similar to the laboratory recovery.

The temperature criterion was not met, as the pattern area was only heated to the 140 to 150°F range. However, it is unlikely that additional coal tar would have been recovered if higher temperatures had been achieved.

Containment of the injected hot water was achieved throughout the operation of the process.

REFERENCES

- Fahy, L.J., L.A. Johnson Jr., D.V. Sola, S.G. Horn, and J.L. Christofferson, 1992, "Bell Pole CROW Pilot Test Results and Evaluation," *Proc.*, Colorado Hazardous Waste Management Society Annual Conference, 15p.
- Gerrish, J.A., 1996, Analytical Results from Brodhead Creek Site Tank Sludge Sampling, September 11, 1996 letter to the United States Environmental Protection Agency, Concord, MA 01742.
- Gruber, W., 1996, "A Fluidized Bed Enhances Biotreatment," *Environmental Engineering World*, March-April 1996, 27-28.
- Johnson, L.A., Jr., and F.D. Guffey, 1990, "Contained Recovery of Oily Wastes (CROW)," Final Report. United States Environmental Protection Agency Assistance Agreement CR-815333, RREL, Cincinnati, OH 45268.
- Johnson, L.A., Jr., and A.P. Leuschner, 1992, "The CROW Process and Bioremediation for In Situ Treatment of Hazardous Waste Sites," *Hydrocarbon Contaminated Soils and Groundwater*, Vol. 2, E.J. Calabrese and P.T. Kostecki, eds., Lewis Publishers, Ann Arbor, MI 343-356.
- Moeller, M.W., J.A. Gerrish, J.F. Villaume, and L.A. Johnson, 1996, "Implementation of a Full-Scale Enhanced Recovery System for Coal Tar at a Former MGP Superfund Site," report to the United States Environmental Protection Agency, Concord, MA 01742.
- Remediation Technologies, Inc., 1996, "Remedial Action Report Brodhead Creek Superfund Site, Stroudsburg, Pa, RETEC Project #1-1190-000, August 1996 report prepared for Pennsylvania Power and Light Co., Concord, MA 01742.
- Villaume, J.F., P.C. Lowe and D.F. Unites, 1983, "Recovery of Coal Gasification Wastes: An Innovative Approach," *Proc.*, Third National Symposium and Exposition on Aquifer Restoration and Groundwater Monitoring, Columbus, OH.