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CROW™ FIELD DEMONSTRATION WITH BELL LUMBER AND POLE

Topical Report

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For
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and
U.S. Department of Energy
Office of Fossil Energy
Federal Energy Technology Center
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By
Western Research Institute
Laramie, Wyoming

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EXECUTIVE SUMMARY

In 1990 efforts were initiated to implement an in situ remediation project for the contaminated aquifer at the Bell Lumber and Pole Company (Bell Pole) Site in New Brighton, Minnesota. The remediation project involves the application of the Contained Recovery of Oily Waste (CROW™) process, which consists of hot-water injection to displace and recover the nonaqueous phase liquids (NAPL).

While reviewing the site evaluation information, it became apparent that better site characterization would enhance the outcome of the project. Additional coring indicated that the areal extent of the contaminated soils was approximately eight times greater than initially believed. Because of these uncertainties, a pilot test was conducted, which provided containment and organic recovery information that assisted in the design of the full-scale CROW process demonstration.

Based on the results from the pilot test the following conclusions were made:

1. The pilot test provided sufficient hydraulic information to design the full-scale CROW remediation system. The pumping test portion of the pilot test indicated uniform aquifer properties. The entire thickness of the aquifer reached the target temperature range, and containment of the injected hot water was achieved.

2. Pre-test injection and extraction rate predictions were achieved.

3. The post-test soil boring data indicated hot-water injection displaced more than 80% of the NAPL near the injection well. The data indicates that a NAPL saturation of approximately 19% (pore volume basis) and a 500-fold decrease in pentachlorophenol (PCP) concentration can be achieved with 20 pore volumes of flushing.

4. The produced water treatment system used during the pilot test was effective in reducing PCP and polynuclear aromatic hydrocarbon (PAH) compounds to concentrations acceptable for sanitary sewer discharge.

5. The microbial assay of the post-test samples found an encouraging increase in microbial population compared to data collected before the pilot test.

Based on the results from the pilot test, conditions and procedures were developed for implementing a full-scale CROW process demonstration to remediate the remaining contaminated soil at the Bell Pole site.

After reviewing the cost ramifications of implementing the full-scale CROW field demonstration, Bell Pole approached Western Research Institute (WRI) with a request for a staged, sequential site remediation. Bell Pole's request for the change in the project scope was prompted by budgetary constraints. Bell Pole felt that even though a longer project might be more costly, by extending the length of the project, the yearly cost burden would be more manageable.

After considering several options, WRI recommended implementing a phased approach to remediate the contaminated area. Phase 1 involves a CROW process demonstration to remediate the upgradient one-third of the contaminated area, which is believed to contain the largest amount of free organic material.

The Bell Pole Phase 1 CROW demonstration is operating satisfactorily. However, due to equipment problems, the system is operating at less than the design conditions and is unable to operate continuously for extended periods of time. Only two pore volumes of hot water and two pore volumes of cold water were injected during 1996. By the end of 1996, over 20,000 gallons of oil had been transferred to the oil storage tank. Bell Pole has also used about 6000 gallons of the produced oil in its pole treating operation.

INTRODUCTION

Beginning in 1990, efforts were initiated for Western Research Institute (WRI) to implement an in situ remediation project for the contaminated aquifer at the Bell Lumber and Pole Company (Bell Pole) Site in New Brighton, Minnesota. The remediation project involves the application of the Contained Recovery of Oily Waste (CROW™) process, which consists of hot-water injection to displace and recover the non-aqueous phase liquids (NAPL) (Johnson and Sudduth 1989).

Wood treating activities began at the Bell Pole Site in 1923 and have included the use of creosote and pentachlorophenol (PCP) in a fuel oil carrier. Creosote was used as a wood preservative from 1923 to 1958. Provalene 4-A, a non-sludging fuel-oil-type carrier for PCP, was used from 1952 until it was no longer commercially available in 1968. A 5–6% mixture of PCP in fuel oil has been used as a wood preservative since 1952, and a fuel-oil-type carrier, P-9, has been used since 1968.

While reviewing the site evaluation information, it became apparent that better site characterization would enhance the outcome of the project. Additional coring indicated that the areal extent of the contaminated soils was approximately eight times greater than initially believed. Because of these uncertainties, a pilot test was conducted, which provided containment and organic recovery information that assisted in the design of the full-scale CROW process demonstration.

BELL POLE PROJECT CHRONOLOGY

1979	Five monitoring wells were installed by Bell Pole and MacGillis-Gibbs Company.
1983	The Bell Pole New Brighton site was placed on the EPA National Priorities List. Bell Pole signed a consent order and agreed to voluntary site remediation and began site cleanup and removal of disposal areas.
September 1985	The groundwater purge well, PW-1 was installed and pumping tests were conducted. Bell Pole subsequently pumped approximately 2000 gallons of free organic product over the next few years.
April 1986	Conestoga-Rovers & Associates Limited (CRA) completed the "Remedial Investigation Phase One Report" for Bell Pole.
February 1989	Bell Pole constructed a rotary kiln incinerator and completed soil incineration operations at the Bell Pole site east yard.

December 1989	Western Research Institute and Bell Pole submitted a proposal to the Department of Energy (DOE) and was awarded funding for a Jointly Sponsored Research (JSR) project to apply CROW process technology to remediate the Bell Pole New Brighton site.
March 1990	CRA completed a site soil boring study indicating the contaminated area was about two acres.
August 1990	CRA and WRI completed for Bell Pole an Interim Response Action Work Plan which was submitted to the Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Health (MDH). This document proposed conducting a 30-day, two-well pilot test to demonstrate the feasibility of using the CROW process to remediate the Bell Pole site.
February 1991	CRA submitted for Bell Pole an Interim Response Action Work Plan for process area soil removal.
April 1991	Bell Pole began operations in its new process plant.
April 1991	At the request of the MPCA, CRA and Bell Pole submitted an Application for Variance Interim Response Action for the CROW process source remediation.
June 1991	Approval to conduct the two-well pilot test of the CROW process was granted by the MPCA and MDH.
September 1991	The two-well pilot test was initiated.
November 1991	The two-well pilot test was completed and the system equipment dismantled.
June 1992	CRA and WRI submitted the Bell Pole CROW 30-Day Pilot Test Report to the MPCA.
July 1992	The Bell Pole CROW 30-Day Pilot Test Report was found acceptable by the MPCA staff.
August 1992	WRI submitted the Bell Pole Pilot Test Evaluation report to DOE.
August 1992	Bell Pole completed the incineration of the process area contaminated soil located above the water table.
June 1993	CRA submitted for Bell Pole a draft of the final design report of CROW and a plan for a phased implementation of the CROW process.
July 1993	CRA and WRI submitted for Bell Pole the final design report of CROW to the MPCA.

August 1993	Bell Pole submitted a permit application to construct the CROW/maintenance building.
November 1993	WRI and CRA completed the drilling and installation of six injection and three monitoring wells at the Bell Pole site.
February 1994	CRA and Bell Pole submitted an application for a variance interim response action to extend the previous variance.
August 1994	WRI completed fabrication of a data acquisition and control system for use by Bell Pole during the CROW field demonstration.
March 1995	Construction for the CROW process system was completed, and groundwater extraction was initiated on a limited basis.
May 1995	Hot-water injection was initiated.
July 1995	Continuous injection/extraction was terminated because sewer discharge criteria were not being met.
February 1996	A hydrogen peroxide injection system was added to the water cleanup system, which resulted in meeting discharge criteria. Groundwater extraction was restarted.
March 1996	Hot-water injection was restarted.
July 1996	Heat exchanger failure occurred. Cold-water injection and extraction continued.
November 1996	Injection and extraction were terminated because of emulsion problems in the oil/water treatment system.

SITE CHARACTERIZATION

Site characterization of the contaminated area at the Bell Pole site has been conducted for several years by Conestoga-Rovers & Associates Limited (CRA) and other consultants. The contaminated soil is contained in the New Brighton Formation (Stone 1966). It has been described as a relatively uniform silty fine-medium grain sand, 23 to 47 feet thick (CRA 1986). The contaminated soil is underlain by the Twin Cities Formation, which is a silty to sandy clay till. The New Brighton Formation is highly permeable, with hydraulic conductivities in the range of 3.1×10^{-3} to 9.5×10^{-3} cm/sec. Conversely, the underlying Twin Cities Formation has low permeability, with a conductivity on the order of 1.0×10^{-7} cm/sec (CRA 1986). The underlying clay till has provided an effective lower boundary to fluid migration and has been responsible for limiting the downward migration of the organic material.

A continuous aquifer lies at a depth of 10 to 20 feet below ground surface (BGS). Groundwater flows radially from a pond, located to the northeast, at a velocity of 0.1 to 0.6 ft/day. Across the Bell Pole site the groundwater gradient is 0.004 ft/ft toward the southwest, where the water appears to discharge into a drainage ditch.

In early 1990, 22 boreholes were drilled to define the extent of the contamination. Later, in preparation for the two-well pilot test, one new injection well and three monitor wells were also drilled and cored. Based on the evaluation of the coring data, it appears that the contaminated or saturated interval has an elongated teardrop shape which dips toward the northeast (Figure 1). The maximum thickness in the center of the zone is approximately 25 feet, while the edge of the contaminated zone is only a foot or two thick.

TREATABILITY TESTS

While the coring operations were being conducted, two large samples of contaminated soil were collected. These samples were used to conduct laboratory treatability tests. These flushing tests were necessary to appraise the effectiveness of the CROW process at this site and to determine operating conditions.

For each flushing test, approximately 30 lb of the contaminated site material was packed into a 3.75-in. diameter by 36-in. long reactor tube. The reactor tube was then placed vertically within the reactor shell. During the packing of each reactor tube, a composite sample of the packed material was prepared for organic loading determination. Each test was conducted by establishing water flow at the desired flow rate through the bottom of the tube with the flush water produced from the top of the tube.

Two tests were conducted, one each at a nominal 120°F and 140°F. The operating conditions and results for the two flushing tests are listed in Table 1. The reduction in the organic saturation was essentially the same, 0.53 and 0.54 wt %, even with the variance in the weight percent oil for the pre-test samples ranges, 2.87 to 7.44%.

The initial and post-test samples submitted for PCP analyses show that the decrease in PCP concentration during the flushing tests was higher than the decrease in the total oil phase concentration.

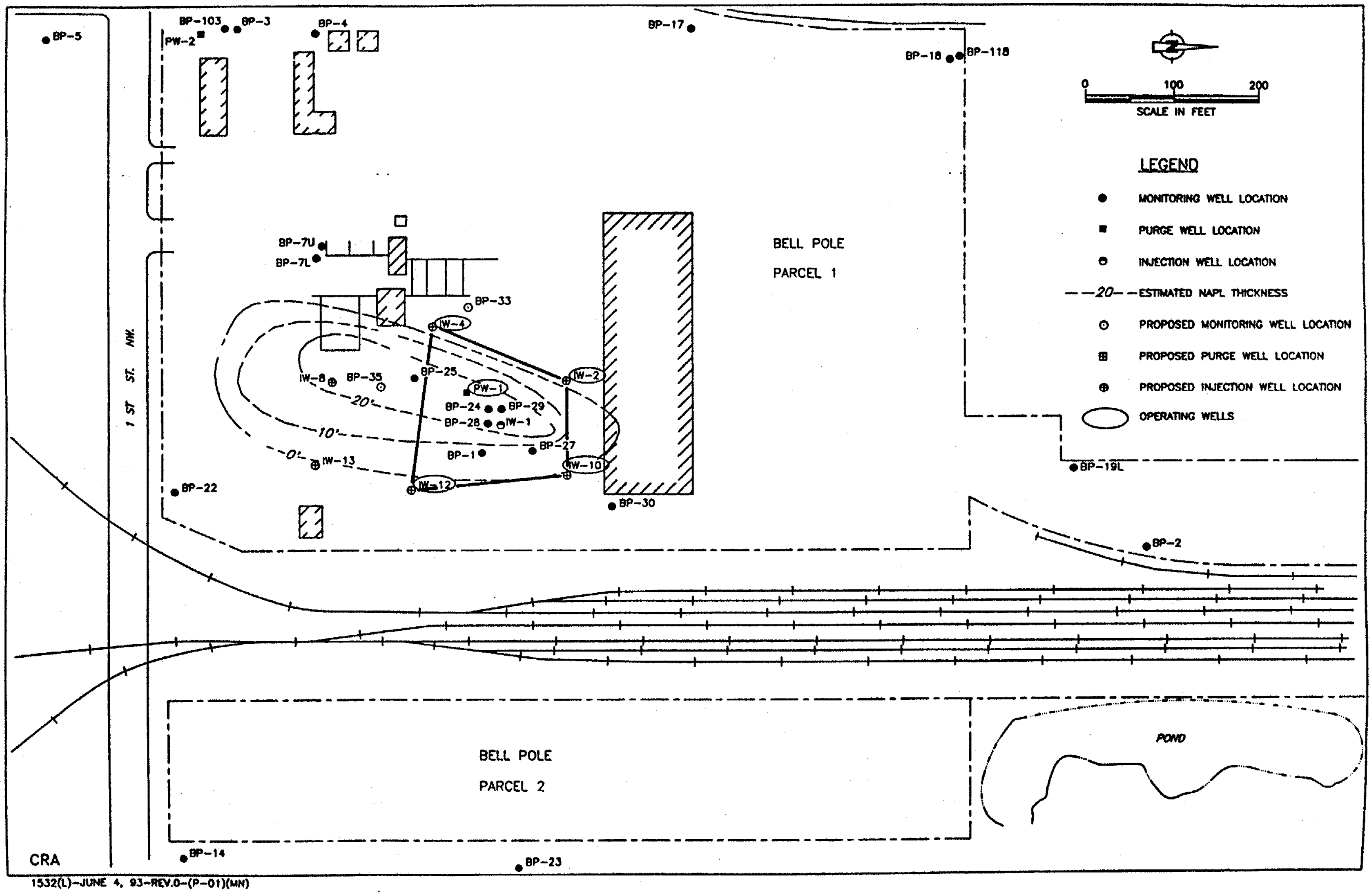

Figure 1. Phase I Well Pattern

Table 1. Process Simulations for Bell Pole

Test Number	103	104
Water Injection		
Temperature, °F	140	120
Flux, cm^3/min	107	118
Velocity, cm/min	$2.5x10^{-2}$	$2.8x10^{-2}$
Porosity, %	35.5	33.6
Initial Oil Saturation of Mobile Oil Zone		
% Pore Volume	42.2	16.2
wt %	7.44	2.87
Residual Oil Saturation		
% Pore Volume	10.0	10.0
wt %	0.54	0.53
Removal of Oil, wt %	93.5	84.3
PCP Concentration, ppm		
Initial Material	3200	1500
Flushed Material	2.3	BDL[a]
% Reduction	99.9	99.8[b]

[a] BDL = Below detection limit

[b] Value based on the flushed material for test 103

PILOT TEST OBJECTIVES

An Interim Response Action (IRA) work plan was prepared in 1990 by CRA and WRI. The IRA detailed how the CROW process would be implemented at the Bell Pole Site (CRA and WRI 1990). Based on the IRA and after the granting of variances by the Minnesota Pollution Control Agency and the Minnesota Department of Health, a two-well pilot test of the CROW process was conducted. The test consisted of injecting hot, potable water into the NAPL-saturated area of the aquifer, producing groundwater (and NAPL) from an existing extraction well, PW1, and treating the produced water for sanitary sewer discharge.

The objectives of the pilot test were to:

1. Compare predicted injection and extraction rates with actual field data;

2. Demonstrate the ability to heat the aquifer to the 120°F to 140°F range;

3. Demonstrate the ability to hydraulically control the injected water to prevent spreading contamination;

4. Confirm treatment system effectiveness in reducing PCP and polynuclear aromatic hydrocarbons (PAHs) prior to sanitary sewer discharge; and

5. Predict anticipated operating conditions for full-scale CROW application.

PILOT TEST DESCRIPTION

The pilot-test location was selected from the site characterization mapping and the location of the existing extraction well, PW1. One new injection well, IW1, was drilled 50 feet upgradient to the northeast from well PW1. Both the injection and extraction wells were located in an area that contained high organic accumulations (Figure 1).

The pilot test began on September 24, 1991. The first step of the test involved pumping the extraction well, PW1. Treatment of water began on September 26, day 3 of the test. Hot-water injection started on day 7 at an initial injection temperature of 147°F. On day 9, the injection temperature was increased to 203°F. Injection was terminated on October 31, day 37 of the pilot test. Pumping continued at PW1 until day 41 when the test ended. Water treatment continued until day 45, and the treatment system was subsequently dismantled.

PILOT TEST RESULTS

Flow rates and injection pressures were recorded by the data acquisition system. The pumping rate at PW1 was started at 5 gpm and stepped up to 9 gpm during the seven days prior to injection startup. During the remainder of the test, PW1 averaged 6.5 gpm (Table 2).

Table 2. Pilot Test Operating Conditions and Results

Total Hot-Water Injection Time	30 days
Average Hot-Water Injection Rate	4.5 gpm
Steady-State Hot-Water Injection Wellhead Temperature	200°F
Total Water Injected	193,000 gallons
Total Water and NAPL Production Time	41 days
Average Fluid Production Rate During Hot-Water Injection Phase	6.5 gpm
First Pumping Test Production Rate	5.0 gpm
Second Pumping Test Production Rate	9.0 gpm
Total Fluids Produced	390,000 gallons
Total NAPL Production	2000 gallons
Areal Extent of Injected Water	3285 ft^2
Time to NAPL Production Response From Start Of Injection	14 days
Time to Breakthrough from Start of Hot-Water Injection	20 days
Average Hot-Water Injection Front Velocity, ft/day	2.5 ft/day

The injection rate was relatively constant during the test and averaged 4.5 gpm. Injection pressure increased during the test from 6 to 14 psig. The hot-water injection temperature remained fairly constant at approximately 200°F for the entire 30 days of injection.

Temperatures were measured at the injection and extraction wellheads and at the monitor well locations. Early temperature data indicated that the hot water might be tending to override and travel predominantly across the top of the aquifer. However, the temperatures in the lower intervals of the aquifer increased until at the end of the 30-day injection period, a temperature profile taken between the injection and extraction wells showed a very uniformly heated front, indicating that the hot water was not traveling across the top of the zone but was heating the entire interval uniformly.

In all cases, a temperature equal to or greater than the targeted 140°F was achieved in the monitor wells located between the injection and extraction wells. Downhole temperature measurements at well PW1 indicated that 150°F fluids had reached PW1 prior to the conclusion of the hot-water injection phase. While the hot-water front was growing horizontally from the injection well toward PW1, it also expanded vertically. Injection at IW1 occurred into a 15-foot interval between 20 and 35 feet BGS and about 5 feet below the top of the water table. However, by the end of the test, the entire thickness of the aquifer had reached the targeted temperature.

After the test was concluded, two boreholes, CT1 and CT2, were drilled and cored. The borehole locations were chosen to represent portions of the aquifer that received two different amounts of hot-water flushing. CT1 represents the aquifer out to approximately 4 feet from IW1, and CT2 represents the aquifer out to approximately 10 feet from IW1. The samples taken from the two boreholes were extracted to determine residual NAPL saturations. The residual NAPL saturations determined from the two boreholes were compared to initial conditions obtained from the core taken from the injection well, IW1.

PILOT TEST CONCLUSIONS AND RECOMMENDATIONS

Based on the results from the pilot test the following conclusions were made:

1. The pilot test provided sufficient hydraulic information to design the full-scale CROW remediation system. The pumping test portion of the pilot test indicated uniform aquifer properties. The entire thickness of the aquifer reached the target temperature range, and containment of the injected hot water was achieved.

2. Pre-test injection and extraction rate predictions were achieved.

3. The post-test soil boring data indicated hot-water injection displaced more than 80% of the NAPL near the injection well. The data indicates that a NAPL saturation of approximately 19% (pore volume basis) and a 500-fold decrease in PCP concentration can be achieved with 20 pore volumes of flushing.

4. The produced water treatment system used during the pilot test was effective in reducing PCP and PAH compounds to concentrations acceptable for sanitary sewer discharge.

5. The microbial assay of the post-test samples found an encouraging increase in microbial population compared to earlier data collected before the pilot test.

CROW TEST PROCEDURE AND DESIGN

Based on the results from the pilot test, conditions and procedures were developed for implementing a full-scale CROW process demonstration to remediate the remaining contaminated soil at the Bell Pole site.

After reviewing the cost ramifications of implementing the full-scale CROW field demonstration, Bell Pole approached WRI and the MPCA with a request for a staged, sequential site remediation. Bell Pole's request for the change in the project scope was prompted by budgetary constraints. Bell Pole felt that even though a longer project might be more costly, by extending the length of the project, the yearly cost burden would be more manageable.

After considering several options, WRI recommended implementing a phased approach to remediate the contaminated area. Phase 1 involves a CROW process demonstration to remediate the upgradient one-third of the contaminated area, which is believed to contain the largest amount of free organic material. The phased approach to remediating the site is not expected to cause any adverse effects except for extending the time required to complete the entire project.

WELL NETWORK DESIGN

During 1993, WRI drilled four, Phase 1 injection wells and three monitoring wells, plus two Phase 2 injection wells, which are being used as downgradient monitoring wells during the first phase.

By using the existing extraction well, PW1, and the new injection wells, an inverted five-spot pattern was installed (Figure 1). Due to its pre-existing location, PW1 is closer to the downgradient injection wells than to the upgradient injection wells, which is anticipated to enhance the overall capture efficiency of the system. Injection-to-extraction well spacings are approximately 100 feet, which is about twice the spacing utilized during the pilot test.

SURFACE TREATMENT SYSTEM DESIGN

Based on results from the pilot test, plus bench-scale tests conducted by Bell Pole and various vendors, a produced fluid treatment system was designed and installed.

During the pilot test it was observed that a significant amount of oil/water separation was occurring in the 40,000-gallon tank into which all produced oil and water was being pumped. To capitalize on this occurrence, all produced water and oil is pumped into a 40,000 gallon process tank after sulfuric acid has been added to lower the pH to approximately 3.5. Oil is skimmed from the top of the tank and pumped off of the bottom of the tank and then routed to an oil storage tank. This is a batch operation that is performed daily.

Water is continuously pumped from the 40,000 gallon process tank to an air flotation unit where the oily water is aerated and most of the remaining oil and grease, PCP, and organic carbon are removed and recycled back to the 40,000 gallon process tank.

The treated water leaving the air flotation unit is treated with sodium hydroxide, then pumped to a 10,000-gallon equalization tank. From this tank, part of the water, 5 to 10 gpm, is pumped to an ozonation unit, which removes the PCP. The water is then treated with hydrogen peroxide to break down the remaining PAH compounds and is disposed of in the sewer. The water that is not pumped to the ozonation unit is recycled through a boiler/heat exchanger system where it is heated and reinjected. The conceptual design of the water treatment system is shown in Figure 2.

Prior to installing the CROW process system, Bell Pole installed a two-well pump and treat system. The water produced from the pump and treat wells enters the 10,000-gallon equalization tank and is either treated for disposal or reinjected.

CONTROL AND DATA ACQUISITION SYSTEM

For the Bell Pole Phase 1 CROW demonstration, WRI developed and installed a control and data acquisition system (CDAS). This system collects all temperature, pressure, flow, and pH data generated by the process. From this data, the CDAS determines what type of control should be exerted on the process. If required, the CDAS will turn a pump, valve, or alarm on or off as specified by the control logic.

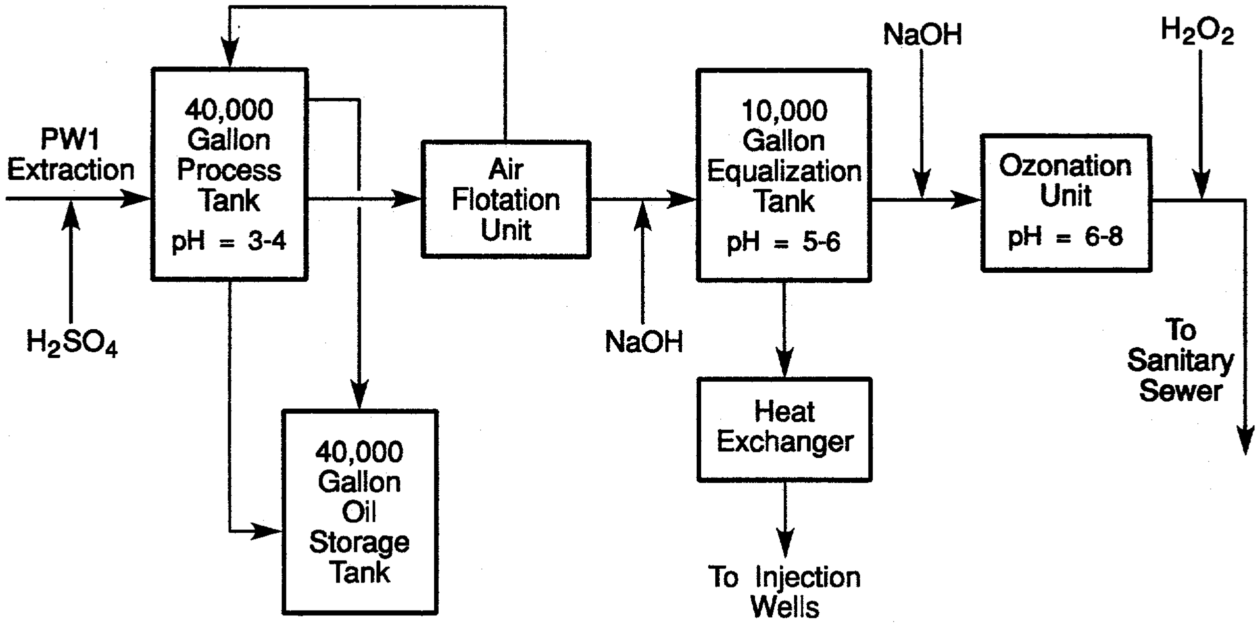

Figure 2. Treatment System Conceptual Design

In addition to controlling the physical process, the CDAS also displays the status of the various parameters on the computer monitor through the use of several computer screens. The system also records the status of these parameters to computer files, which are routinely downloaded via the modem system for analyses and archiving.

From the beginning, the CDAS system operated basically as designed. However, the computer had a tendency to "hang up" occasionally. In October, 1995, an upgrade of the control system and Windows 95.0 were installed. These upgrades have eliminated the previous problems, and the system has been operating trouble free.

PROJECT OPERATION

By early 1995, all of the equipment, except for the hydrogen peroxide system, had been installed. Water extraction began March 1995, and the system was operated intermittently through April 1995. On May 16, 1995, continuous operation of the CROW system began. Continuous hot-water injection was terminated on June 29, and continuous extraction and disposal of excess water was terminated July 12, 1995, because of failure to meet the sewer discharge criteria.

The ozonation unit was originally designed for removal of PCP and has functioned satisfactorily. However, high concentrations of PAHs, particularly naphthalene and phenanthrene, exceeding the discharge criteria were occurring. After several attempts to reduce the PAH concentration in the discharge water, the hydrogen peroxide injection system was installed downstream of the ozonation unit. Hydrogen peroxide injection brought the PAH concentrations down to acceptable discharge limits (Table 3).

Table 3. Water Disposal PAH Concentration, mg/L

PAH Compound	Before Hydrogen Peroxide Injection	After Hydrogen Peroxide Injection	Discharge Limits
Naphthalene	3900	630	3000
Acenaphthene	530	40	3000
Fluorene	[1]BDL	340	3000
Pentachlorophenol	BDL	280	3000
Phenanthrene	5200	780	3000
Anthracene	340	37	3000
Fluoranthene	1100	360	3000
Pyrene 1400	370	3000	
Benzo-a-anthracene	260	57	3000
Chrysene	340	110	3000
Benzo-b-fluoranthene	BDL	23	3000
Benzo-k-fluoranthene	BDL	60	3000
Benzo-a-pyrene	BDL	14	3000
2-Methylnapthalene	1400	290	3000
Total PAH Concentration	14470	3391	10000

[1]Below Detection Limits

Once it was demonstrated that the discharge criteria could routinely be met, the water contained in the water treatment system was treated and disposed of, and extraction from PW1 was restarted. Continuous groundwater extraction was established February 26, 1996, and continuous hot-water injection began a week later on March 4, 1996.

On March 12, 1996, the entire water treatment system was analyzed for oil and grease concentration and partially analyzed for PCP and total PAH concentration (Table 4). The extraction well, PW1, oil and grease concentration was uncharacteristically low, suggesting groundwater pumping prior to hot-water response has lowered the oil concentration in the immediate area. PW1 oil and grease concentrations had typically been in the 1000 to 3000 mg/L range when sampled. The oil and grease concentration after the air flotation unit was reduced significantly compared to earlier results and this is attributed to operating at a lower pH.

Table 4. Process Train Hydrocarbon Sampling
March 13, 1996

PW1 Effluent		
Oil and Grease Concentration, mg/L		300
After Air Flotation Unit		
Oil and Grease Concentration, mg/L		71
Injection Water		
Oil and Grease Concentration, mg/L		96
PCP Concentration, mg/L	10	
Discharge Water		
PCP Concentration, mg/L	<1	
Total PAH Concentration, mg/L		<4

Continuous hot-water injection was terminated on July 15, 1996, following a heat exchanger failure. At that time, aquifer temperatures were approaching 120°F, and 70°F water was being produced at the extraction well. Cold-water injection and groundwater extraction continued while efforts were made to replace the heat exchanger. The entire system was shut down November 8, 1996, because of problems caused by oil/water emulsion in the water treatment system.

During this shutdown period, the 40,000-gallon process tank is being heated, and the oil/water emulsion is slowly being broken. The oil is being transferred to the oil storage tank and the produced water treated and sent to the sewer. A new heat exchanger is being procured and should be available soon, at which time the CROW system will be restarted.

DISCUSSION

The Bell Pole Phase 1 CROW demonstration is operating satisfactorily. However, due to equipment problems, the system is operating at less than the design conditions and is unable to operate continuously for extended periods. When the replacement heat exchanger is brought online, efforts will be made to increase the injection temperature to the 195-200°F range, which will improve the aquifer temperature response.

Only two pore volumes of hot water and two pore volumes of cold water were injected during 1996. Actual injection and extraction fluid rates have been 11 and 14 gpm, respectively. These conditions are about half the original designed operating conditions. At the current rates, it will take another 30 months to complete 20 pore volumes of injection. The Bell Pole CROW test summaries are shown in Tables 5 and 6.

Table 5. Bell Pole CROW Test Summary
January 3, 1995 through February 25, 1996

Total Water Injected, gal	222,811
Total Fluid Extracted, gal	642,138
Total Water Disposed, gal (Includes Off Pattern Pump and Treat Production)	543,315
Total Water Inventory in Tanks, gal	25,890

Table 6. Bell Pole CROW Test Summary
February 26, 1996 through December 31, 1996

Continuous Extraction Time, days	257
Hot-Water Injection Time, days	134
Cold-Water Injection Time, days	116
Average Hot-Water Injection Temperatures	
Heater Temperature, °F	172
Injection Manifold Temp, °F	171
IW4 Injection Line Temp, °F	165
Maximum PW1 Aquifer Temp, °F	78
Injection Well Aquifer Temp Range (measured 7/11/96), °F	166-175
Total Hot-Water Injected, gallons	4,103,856
Total Fluid Extracted, gallons	5,288,544
Total Water Disposed, gallons (Including Off-Pattern Pump and Treat Production)	1,670,883
Average Pattern Water Injection Rate, gpm	11.2
Average Pattern Water Extraction Rate, gpm	14.1
Average Water Disposal Rate, gpm (Including Off Pattern Pump and Treat Production)	4.3
Individual Injection Well Flow Rates (Normalized Values), gpm	
IW2	2.8
IW4	1.9
IW10	3.7
IW12	2.8
Cumulative Product Recovery Estimate, gal (excluding oil in Process Tank)	20,000

Based on the aquifer temperature measurements, an areal temperature contour map was prepared (Figure 3). The high temperature front was arbitrarily defined by the 75°F temperature contour. While there are a number of monitoring wells within the pattern area, the data are limited, making the contours somewhat interpretive.

However, the data does suggest some important trends. First, the hot-water injection period has not progressed long enough to establish an interconnected hot-water front or fronts. Second, the majority of the high temperature measurements in the pattern appear to be influenced by injection into IW10. However, the relatively low temperature response at PW1 indicates the extraction well was mainly influenced by the injection at IW2. Third, the more downgradient wells, IW4 and IW12, will require a longer time and more injected pore volumes before they noticeably affect the extraction well, PW1. Fourth, the aquifer temperature data confirms that the injected water is contained within the pattern area.

Monitor well BP27, which is located on a line between wells IW10 and PW1, experienced the greatest temperature response. Figure 4 shows the aquifer temperature profile at different times before and after termination of hot-water injection. As expected, the aquifer is returning to ambient temperature without the injection of hot water.

Oil production has been estimated daily from the transfer of oil from the process tank to the oil storage tank. An actual daily rate has been difficult to determine because the oil remaining in the production tank after oil transfer can only be estimated. By the end of 1996, more than 20,000 gallons of oil had been transferred to the oil storage tank. Bell Pole has used about 6000 gallons of the produced oil in its pole treating operation.

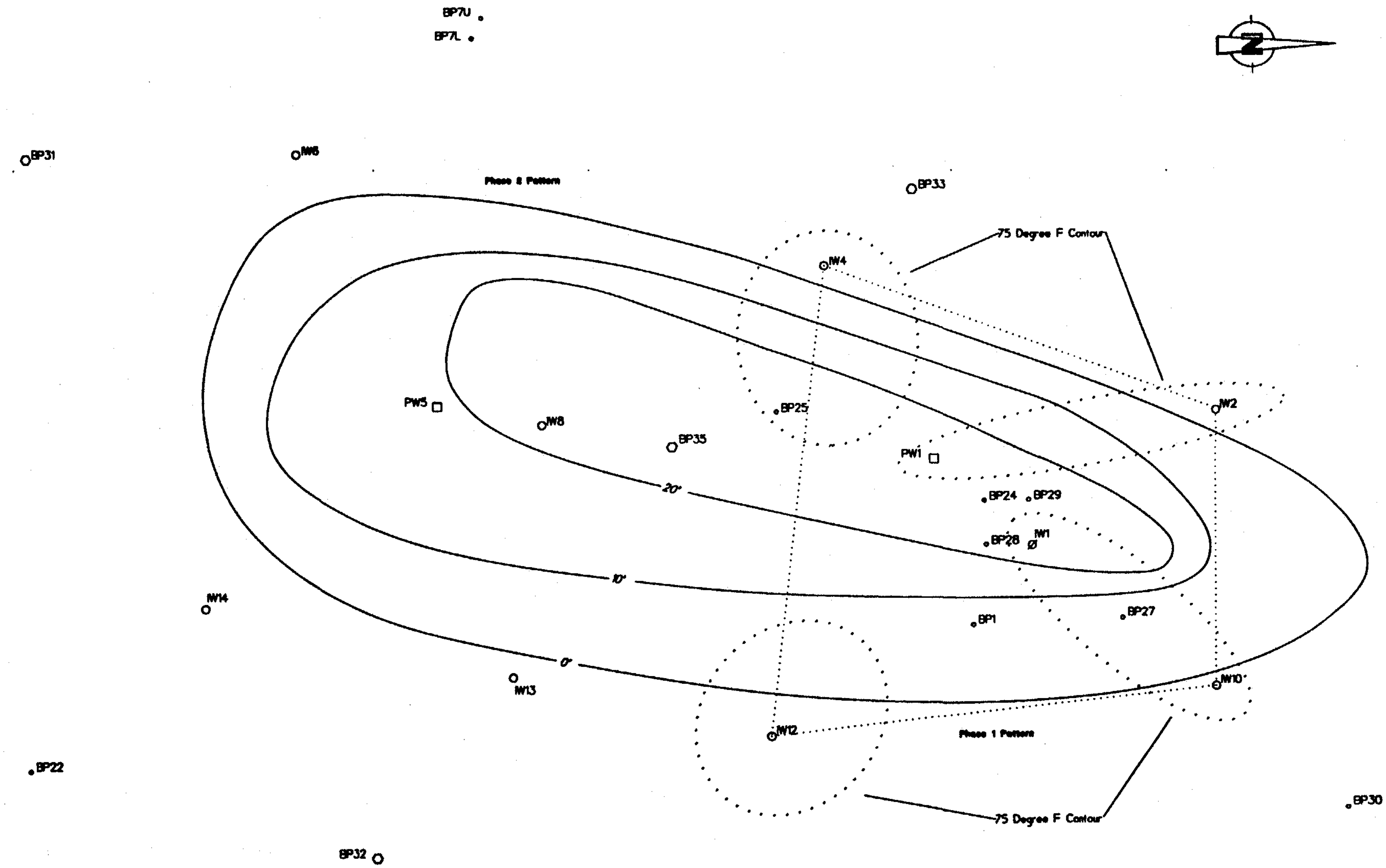

Figure 3. Aquifer Areal Temperature Contour Map

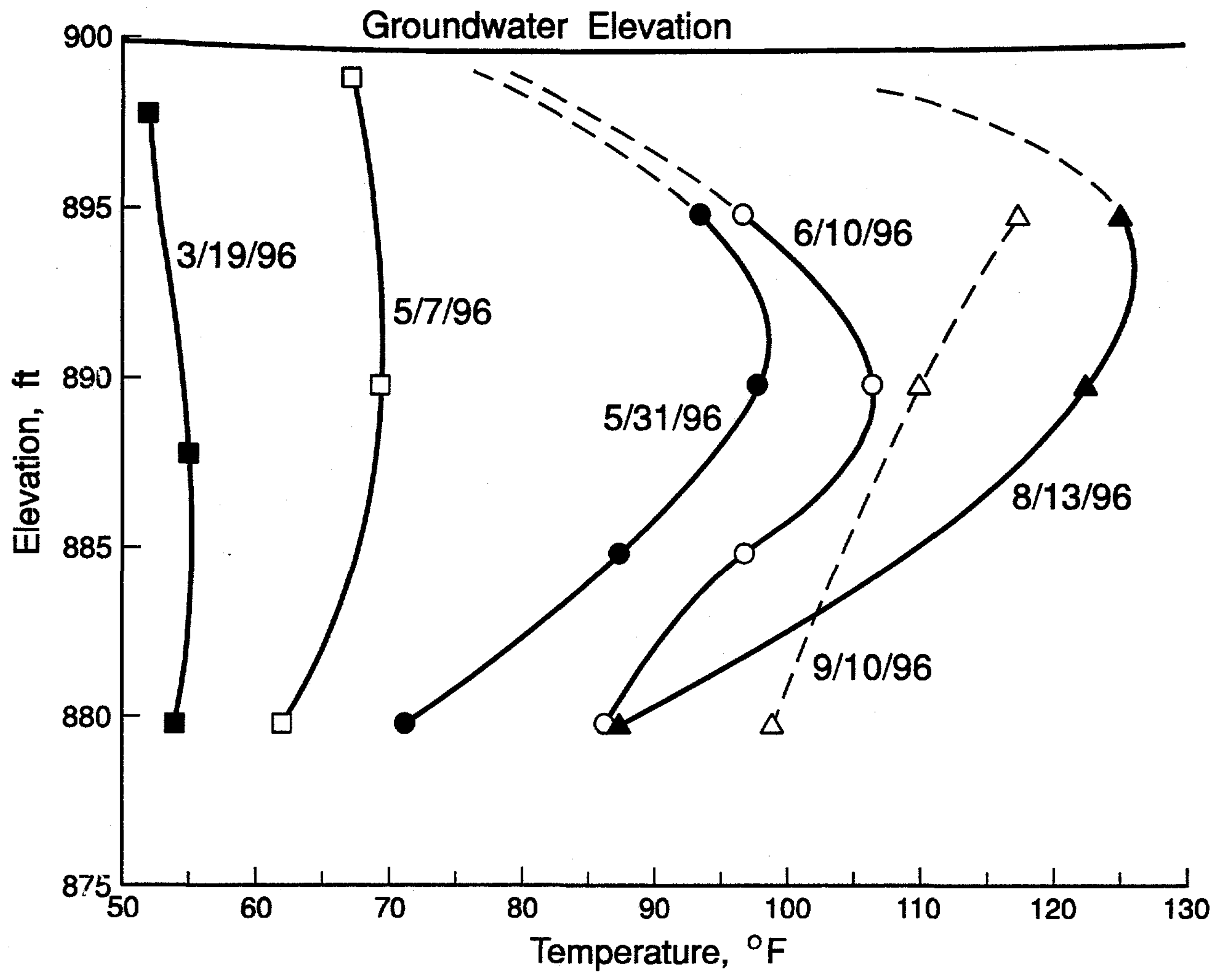

Figure 4. Monitor Well BP27 Aquifer Temperature Profile

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