INNOVATIVE STRATEGIES FOR THE REMEDIATION OF CHLORINATED SOLVENTS AND DNAPLS IN THE SUBSURFACE

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S.M. Henry and C.R. Bennett

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ELECTROCHEMICAL REMEDIATION TECHNOLOGIES FOR SOIL, SEDIMENT AND GROUND WATER

Falk Doering[2], Niels Doering[2], Joe L. Iovenitti[1], Donald G. Hill[1],
William A. McIlvride[1] and Rod I. Satre[1]
[1]Weiss Associates, 5801 Christie Avenue, Suite 600, Emeryville, CA 94608
Fax: 510-547-5043, jli@weiss.com
[2]P2-Soil Remediation, Inc.

INTRODUCTION

ElectroChemical Remediation Technologies (ECRTs) are phenomena related to colloid electrochemistry and belong to the class of Direct Current Technologies (DCTs) where direct current electricity is passed between two electrodes. The primary distinctions between ECRTs and traditional electrokinetics are the (1) operative mechanisms, (2) energy input, (3) nature of the direct current, and (4) resulting outcome.

ECRTs are patented in the United States and Europe and include the ElectroChemical GeoOxidation (ECGO) process to destroy organics in soil, and the Induced Complexation (IC) process to mobilize and remove metals in soil and ground water. ECGO is employed in ground water remediation with a complementary technology comprising carbon dioxide vacuum stripping (CVS) wells, with or without electrolytic destruction (CVS-1 and CVS-II wells, respectively).

ECRTs have been successfully applied to soil, sediment, and ground water both *in-situ* and *ex-situ*. Among the contaminants remediated to below regulatory standards are VOCs, CVOCs, SVOCs, PAHs, PCBs, phenols, fuels, other hydrocarbons, explosives, mercury, cadmium and lead. In many of the more than 50 successful projects, multiple contaminants have been removed with a single system, including combinations of metals and organics. ECRT projects are documented, ISO 9001-certified and insurable.

TECHNICAL BASIS

Figure shows that ECRTs consume very little energy compared with other, conventional electrokinetic remediation mechanisms.

When the low voltage and low amperage, coupled DC/AC field is introduced to the electrodes in soil and/or ground water, an induced polarization field is created. When this occurs, the soil acts as a capacitor, discharging electricity. Figure is an oscillogram showing measured voltage and amperage in soil.

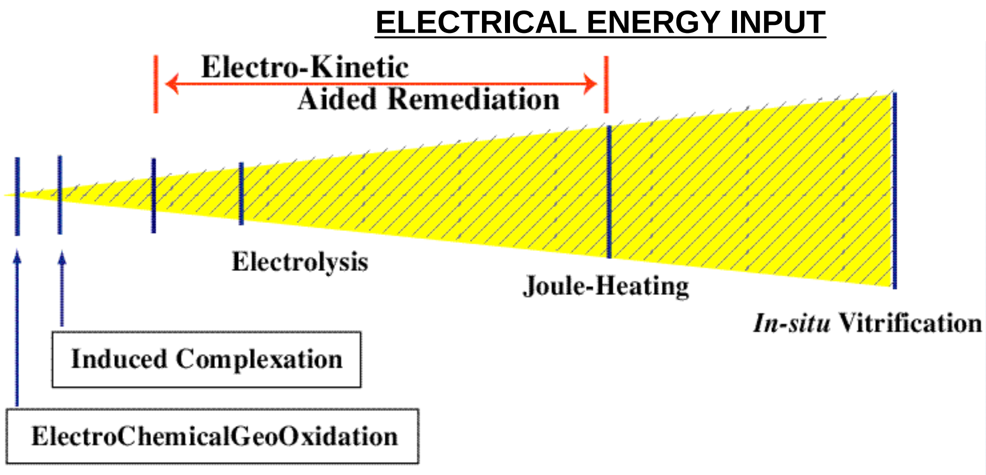

Figure 1. Relative Electrical Energy Input Scale

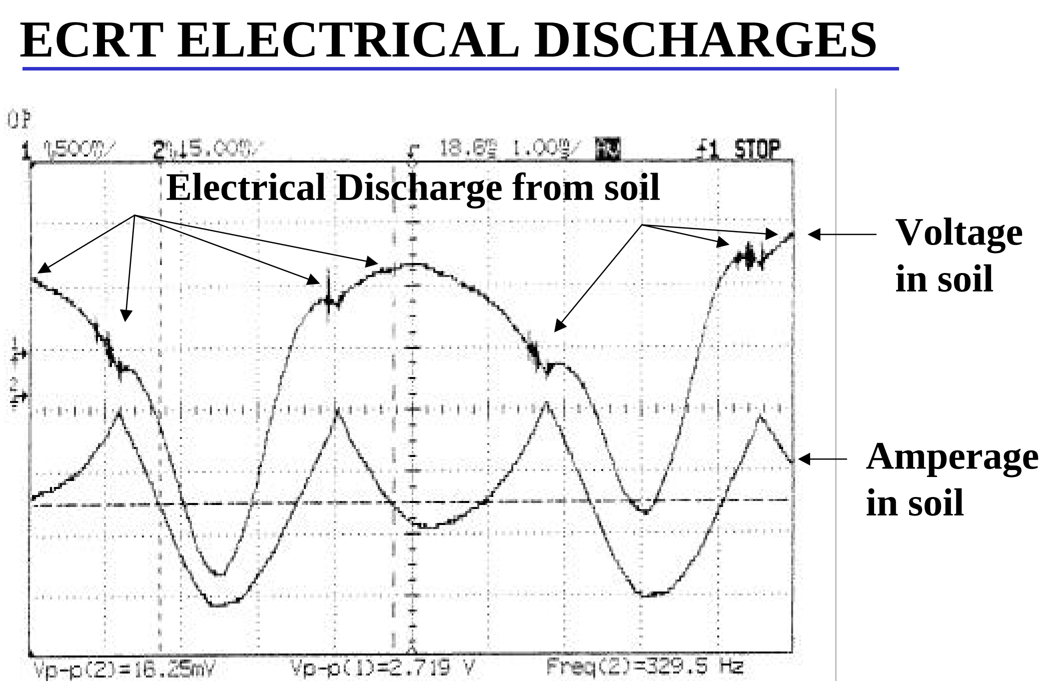

Figure 2. Electrical Oscillogram Demonstrating Soil Electrical Discharges

When electrical power is being supplied to the soil by the AC/DC converters, the voltage and amperage are in phase (i.e., track each other) but when the soil is discharging electricity, spikes in the voltage curve appear and the voltage is "out of phase" relative to the amperage. It is the discharge of electricity from the soil that causes the redox reactions in the soil matrix. The reaction rates are inversely proportional to grain size, such that ECRTs remediate faster in clays and silts than in sands and gravels.

The three subtypes of ECRTs employ this redox mechanism as follows:

ElectroChemicalGeoOxidation (ECGO) relies solely on the mechanism to directly destroy organic contaminants in soil and to some extent in ground water. Reaction products if taken to completion include carbon dioxide, water, and, in the case of chlorinated compounds, chloride ion.

Induced Complexation (IC) uses the mechanism to form metals complexes from the contaminants, rendering them more mobile. The increased mobility is exploited by the induced current, which plates the metals complexes onto the electrodes.

Carbon Dioxide Vacuum Stripping (CVS) wells, when used in conjunction with ECGO, employ the mechanism to remove contaminants from ground water.

BENEFITS OF ECRTS

- Cleanup is rapid, on the order of months, requiring less energy than electrokinetic methods, and at costs well below conventional remediation such as excavation.
- A wide range of COCs, including metals and organics, can be treated with one system.
- ECRTs work *in-situ* or *ex-situ*, in all soil types, generally produce no regulated waste streams, are safe, quiet, and do not interfere with surface activities.
- ECRT projects are well documented, ISO 9001-certified, and insurable.

REMEDIATION EXPERIENCE

Presented below are case histories of just two of more than fifty successful projects.

PAH Remediation

In Enns, Austria, approximately 500 tons of excavated soil contaminated with polynuclear aromatic hydrocarbons (PAHs) and their derivatives, consisting of silt and fine sand, were piled approximately 12 m x 14 m x 3 m high. Sampling and analysis by GC/MS indicated that the maximum soil concentration of US-EPA 116 PAHs (EPA Method 8270) averaged 1354 mg/kg. Two sets of electrodes were installed in the pile approximately 6.2m apart, and energized by the ECGO AC/DC converter.

The remediation was completed in 70 days, when the average total PAHs (1-16) concentration in the soil was 55 mg/kg. The cleanup objective was 100 mg/kg. Table 1 presents the results of soil sampling by the local regulatory agency.

Chlorinated Organics Remediation

The site is a lignite carbonizing plant and oil refinery located in an area of abandoned and collapsed mines where soft coal was produced until 1936. The site is underlain by fine sand to a depth of 15 feet, and fine marl from 15 to 95 ft depth. The water table is at approximately 25 ft depth, and the hydraulic conductivity of the marl approximately 1 x 10^{-6} cm/sec. The soils were heavily contaminated with phenols, petroleum hydro-carbons, and chlorinated VOCs (CVOCs) including PCE, TCE, DCE, DVCE, and vinyl chloride, and an LNAPL of 1.7 ft thickness was present on the ground water.

Table 1. Regulator's Chemical Analysis Results Results

Days	1	36	70
Naphthalene	80.7	81.3	17.29
Acenaphtylene	35.2	44.1	0.98
Acenaphthene	9.8	22.2	0.6
Fluorene	38.6	503.1	1.13
Phenanthrene	326.8	83.7	7.35
Anthracene	47.8	11.9	1.45
Fluoranthene	107.5	23.4	2.98
Pyrene	230.2	81	8.38
Benzo(a)anthracene	71.3	17.6	1.48
Chrysen	81.8	17.9	2.04
Benzo(b)fluoranthene	50.7	9.6	2.09
Benzo(k)fluoranthene	47.3	4.2	1.21
Benzo(a)pyrene	110.3	17.9	3.75
Indeno(123-cd)pyrene	47.8	26.2	1.09
Dibenz(ah)anthracene	9.5	25.6	2.98
Benzo(ghi)perylen	59.5	37.9	0.54
Total PAHs (1-16)	1354.8	1007.6	55.33

Note: All concentrations are in milligrams per kilogram (mg/kg)

A pilot array consisting of two electrodes 27 ft apart and 94 ft deep was installed and energized. Soil samples were collected from boreholes between the two electrodes at 5 to 10-ft intervals, to a depth of 95 ft. After 73 days, the LNAPL had completely dissolved and at all sampling intervals contaminant concentrations were well below baseline (Table 2).

Following this pilot, a full-scale remediation was implemented in one of the most contaminated areas of the site. Thirty-nine electrodes, comprising an ECGO/CVS-II system, were placed in an area of approximately 15,000 square feet to a depth of 200 ft. The soils were contaminated with phenols up to 2,100 mg/kg, TPH up to 5,300 mg/kg, CVOCs up to 48 mg/kg, and BTEX up to 320 mg/kg. Portions of the soil were saturated with an oily fluid containing the above chemicals as well as PAHs. An LNAPL ranging in thickness from 3 to 4.5 ft was present on the water table.

Table 2. Site Contaminant Concentrations

Remediation Time	Phenols (mg/kg)	TPH (mg/kg)	Total CVOCs[1] (mg/kg)
Baseline	355–330.9	135.4–438.6	5.7–23.1
After 73 days	<0.1–1.55	1.7–40.6	<0.5–5.2

[1]Chlorinated volatile organic compounds

Cleanup levels were established at 10 mg/kg for phenols, 300 mg/kg for TPH, and 8 mg/kg for CVOCs. After 40 days of operation of the ECRT system, the LNAPL had completely dissolved, and after 65 days, concentrations of all COCs including PAHs were below the cleanup levels. Approximately 162,000 metric tons of soils were treated. The regulatory authorities accepted the remediation.

SUMMARY AND CONCLUSIONS

ECRTs, while relatively new in North America, have been proven successful in remediating a wide range of contaminants, including chlorinated compounds dissolved in ground water. The advantages of ECRTs include cost effectiveness, relatively short remediation times, and either *in-situ* or *ex-situ* capability. Remediation has been achieved in soils, ground water, and sediments.

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