

## Electrode assisted soil washing

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### Abstract

Contaminants in soils containing a high percentage of silt- and clay-sized particles typically are strongly adsorbed and very difficult to remove. However, a newly patented Electrode Assisted Soil Washing (EASW) process appears to be effective in removing petroleum hydrocarbons (gasoline, diesel, crude oil, etc.), chlorinated hydrocarbons, and heavy metals [7] from contaminated soils made up of a high percentage of clay and silt. The EASW process produces a washed soil material that meets site-specific regulatory requirements which allow the washed soil to be returned to the site without further treatment. Furthermore, the contaminated water generated by the process can be treated with standard biological methods. The EASW process can be used alone, or it can be used in combination with other soil-washing methods. In the latter case, the EASW process is particularly effective in the treatment of contaminated fines streams generated by other soil-washing techniques. The results of bench-scale batch tests with EASW used for washing petroleum hydrocarbons and pentachlorophenol contaminated soils will be discussed in this paper. Contaminant removal efficiencies of the EASW process, based on the difference between the contaminant concentrations in the feed soil and the washed soil, were above 99%. The performance of the EASW process in removing pentachlorophenol from soil was benchmarked against a commercially available process and found to be competitive.

*Keywords:* Soil washing; Ex-situ; Clays; Hydrocarbons; Electrodes

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### 1. Introduction

The patented EASW process was developed to address the remediation of contaminated soils classified as clays or sandy clays. According to EPA standards, these soils are the most difficult to wash because they consist of over 50 wt% of silt and clay [1]. Particle size distribution of the soil is a standard physical characterization criteria that is often used to determine the effectiveness of soil-washing technologies. Fig. 1

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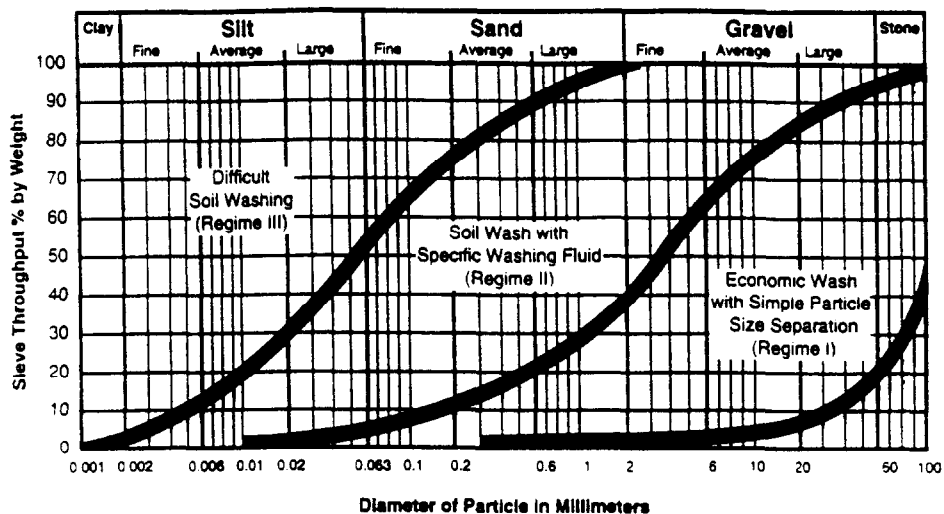


Fig. 1. Ranges of soil-washing difficulty.

Table 1  
Percentage of clay and silt in test soils

	Soil type			
	EPA Regime III <sup>a</sup>	Lubbock soil	Gulf Coast	New Jersey
Clay (wt%)	3	31	39	30
Silt and Clay (wt%)	52	62	53	40
Sand and Gravel (wt%)	45	7	8	30

<sup>a</sup> Clay, silt, and sand content of soils in EPA Regime III. Numbers greater than these for any soil indicate that it will be difficult, or even impossible, to wash the soil by the existing technologies.

[1] shows the varying levels of soil-washing difficulty, classified according to the particle size distribution of the contaminated soil.

Table 1 shows the clay and silt content present in the soils that were treated with the EASW process. The numbers in the first column are representative of the EPA Regime III in Fig. 1. According to EPA criteria, any soil having a higher percentage of clay and silt than a Regime III soil will be very difficult, if not impossible, to wash. All of the soil samples, tested on the EASW process, contained significant fractions of fine silt and clay. This should make them very difficult to wash. The level of difficulty of washing the soils tested on the EASW process is represented in Fig. 2.

Initial tests on the EASW process were accomplished using uncontaminated Lubbock top soil which was artificially contaminated with specific amounts of diesel fuel or crude oil. Artificially contaminated soils have been used by other workers [2]. Subsequent tests have been performed on soils from documented sites contaminated with petroleum hydrocarbons. This approach demonstrated that the EASW process

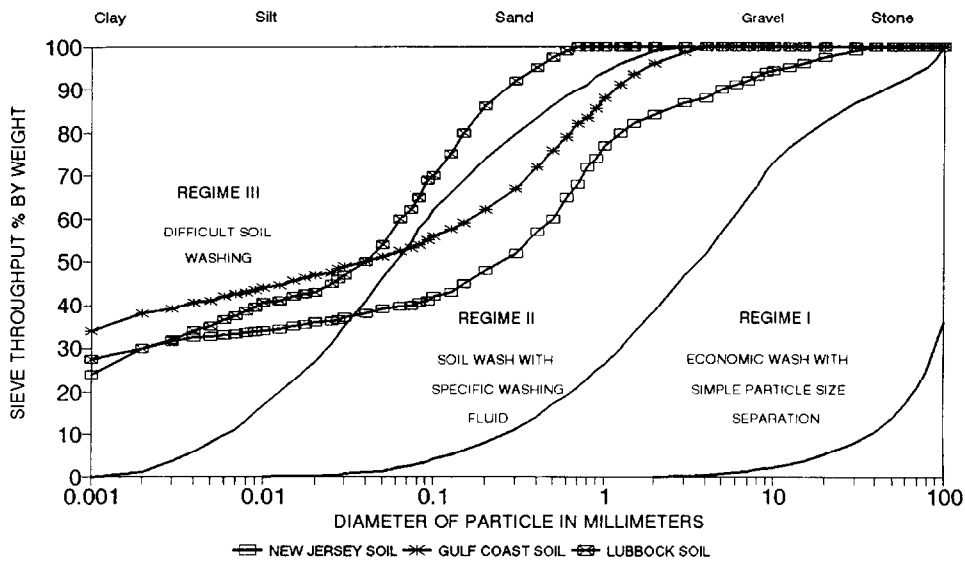


Fig. 2. Soil-washing difficulty of the EASW test soils.

also works on field soil samples. Bench-scale results of the EASW process have shown that the process is capable of reducing the hydrocarbon contaminants adhering to these soils to levels under 100 parts per million.

## 2. Process description

The continuous process schematic is shown in Fig. 3. The results reported in this paper are for the batch EASW process. Fig. 4 shows the batch EASW unit used. In this process, the contaminated soil is screened to remove hard rocks, gravel, scrap metal, etc. Recycled water is added to the screened soil to make a slurry. In a batch EASW run, 600 ml of water is used for 80 g of the contaminated soil. A three percent by weight of potassium carbonate is added to the soil to maintain a suitable pH and to make the soil slurry electrically conductive. The slurry is sheared in a high-speed mixer for 30 s, to make a homogenous suspension. The soil slurry is then transferred to the EASW unit for treatment. The EASW process unit produces three streams after treatment, one of which is composed of water vapor and small amounts of volatiles which may be released by the process. The second stream is composed of the contaminated water which is usually recycled as necessary. Washed soil, which meets site specific regulatory requirements, comprises the third stream.

The EASW process employs volume boiling of the soil–water slurry to energize washing of contaminants such as hydrocarbons, chlorinated hydrocarbons, and heavy metals from the soil. Volume boiling is achieved by causing an AC electric current to flow through the soil–water slurry [4, 5]. This electric current results in boiling

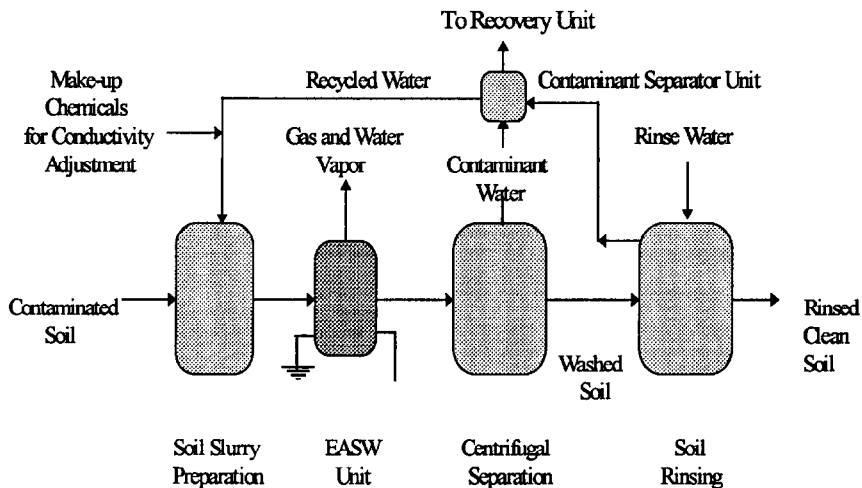


Fig. 3. Process schematic for the EASW process.

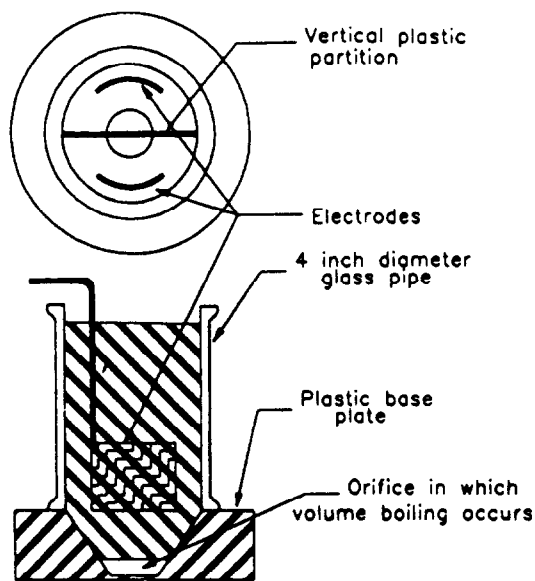


Fig. 4. EASW batch unit.

occurring within the volume of the soil–water slurry between the electrodes, due to resistive heating, not conventional boiling on an externally heated surface. The novel design of the EASW cell facilitates an intense scrubbing of the contaminated soil particles. This action aids in chemical oxidation and mineralization of the hydrocarbons and transfers the modified contaminants to the liquid phase of the soil–water

slurry. The slurry is then fed to a centrifuge that separates the bulk of the water carrying the contaminants from the suspended solids. The treated soil is then reslurried with clean water in subsequent wash stages and centrifuged until the desired degree of decontamination is achieved. The soil rinsing step uses about 2 ml of fresh water per gram of the soil to be rinsed. The rinsing should be done in a countercurrent manner so that a minimum amount of rinse water is required. The rinse water and the contaminated water are treated, if necessary, before recycling. The treatment will remove contaminants which may build up in the water as a result of continuous recycle. Different treatments will be required for different contaminated soils. Possible treatments are flocculation to remove dispersed clays, precipitation of dissolved metals, skimming of insoluble organics, biological treatment to remove dissolved organics, etc. In many cases, it will be possible to just treat a side stream of the recycled water and not the entire recycled stream. The EASW process has been operated on bench-scale both as a batch and as a continuous process.

Table 2  
Results from the EASW process for petroleum hydrocarbons

Hydrocarbon	Soil source			
	Clean Lubbock top soil with		Gulf coast <sup>a</sup> Unknown HC <sup>c</sup>	New Jersey <sup>b</sup> Unknown HC
	Diesel	Crude oil		
Analysis (TPH) <sup>d</sup>	ppm <sup>e</sup>	ppm	ppm	ppm
Untreated soil	47 620	15 000	38 710	4357
High-speed mixing <sup>f</sup>	7820	8094	1080	NA <sup>g</sup>
			980	
			710	
Conventional boiling <sup>f</sup>	1470	1049	305	NA
	1200	1092	325	
	1200			
Treatment with EASW process <sup>f</sup>	122	ND <sup>h</sup>	34	43
	46	ND	22	13
	60	3	46	
	18	18	38	

<sup>a</sup> Soil from a 'tar-pit' of a major Gulf Coast petrochemical producer. This was received as a slurry with oily material floating on top. When dried, the soil set up like cement. This was a rather difficult sample to work within the laboratory.

<sup>b</sup> This was a soil removed from a location at products loading terminal. Reportedly, the residual hydrocarbons in the soil were not readily biodegradable.

<sup>c</sup> Unknown source and type of hydrocarbons.

<sup>d</sup> Total petroleum hydrocarbons. EPA method 418.1 (Spectrophotometric, Infrared).

<sup>e</sup> Parts per million.

<sup>f</sup> The results vary within each block of data due to changes in process parameters, such as soil slurry concentrations, as well as due to random scatter of the experimental data.

<sup>g</sup> Data not available.

<sup>h</sup> Non-detectable levels of Total Petroleum Hydrocarbons (TPH).

Table 3  
Effluent water analysis

Sample No.	Biological Oxygen Demand (BOD <sub>5</sub> ) (ppm)	Total Organic Carbon (TOC) (ppm)	Chemical Oxygen Demand (COD) (ppm)
1	81	164	314
2	90	65	334
3	144	72	310
4 <sup>a</sup>	700	450	1400

<sup>a</sup> Typical chemical-plant-wastewater [3].

### 3. Results with petroleum hydrocarbons

Table 2 summarizes the results of the bench-scale tests using the EASW process for washing crude oil contaminated soil. Lubbock top soil, sieved to minus 0.2 mm using US standard sieves, was used as the soil matrix. A 26.2 API crude oil was used to contaminate the soil matrix. The crude oil was provided by the Fina Refinery at Big Spring, TX. The pH of the effluent water from the EASW process was 10. The temperature of the treated soil slurry was 97 °C.

Performance of the EASW process is compared with that of high-speed mixing and/or conventional boiling of a soil slurry followed by centrifuging. Based on these data, the EASW process clearly outperformed the two alternative processes for each of the soils that were tested.

The process-wash-wastewater produced by EASW treatment was analyzed for its level of contamination and the results are summarized in Table 3. Values for the Biological Oxygen Demand (BOD<sub>5</sub>), Total Organic Carbon (TOC), and Chemical Oxygen Demand (COD) of the process-wash-wastewater from the EASW process are significantly lower than the levels listed for a typical chemical-plant-wastewater [3]. This indicates that the effluent waste-water can probably be treated by normal biological processes.

### 4. Test results with pentachlorophenol

The bench-scale results of the EASW process for washing pentachlorophenol (PCP) contaminated soils are summarized in Table 4. Lubbock top soil, sieved to minus 0.2 mm using US standard sieves, was once again used as the soil matrix. A 99% pure laboratory grade pentachlorophenol was used as the contaminant. The EASW process was very effective in washing this synthetically contaminated soil. Removal efficiency for the EASW process was defined as follows:

$$\% \text{ Removal efficiency} = \left\{ 1 - \frac{\text{Contaminant weight in washed soil}}{\text{Contaminant weight in feed soil}} \right\} \times 100.$$

Table 4  
Results from the EASW process for pentachlorophenol

	Weight (g)	Pentachlorophenol		
		Concentration <sup>a</sup> (ppm)	Mass <sup>b</sup> (mg)	(% <sup>c</sup> )
<i>Inputs</i>				
Feed soil	120.0	15000.0	1800.0	100.0
Water	1850.0	0.0	0.0	0.0
Potassium carbonate	3.9	0.0	0.0	0.0
Methanol	31.6	0.0	0.0	0.0
Total	2005.5		1800.0	100.0
<i>Outputs</i>				
Washed soil	167.5	81.0	13.6	3.3
Contaminated water	1720.0	230.0	395.6	96.7
Water vapor <sup>d</sup>	118.0	0.0	0.0	0.0
Total	2005.5		409.2	100.0
% Removal of PCP from soil – 99.2				
% PCP apparently destroyed – 77.3				

<sup>a</sup> Refers to the concentration of pentachlorophenol present in each weight fraction of the input or output.

<sup>b</sup> Refers to the mass of pentachlorophenol present in each weight fraction of the input or output.

<sup>c</sup> Refers to the percent of total input or output of each weight fraction.

<sup>d</sup> This just reflects the difference between the total inputs and the total outputs.

The EASW process yielded removal efficiencies of over 99%. Mass balances shown in Table 4 indicate that 99.2% of the pentachlorophenol originally present in the contaminated soil was removed by the EASW process. The effluent water would normally be expected to contain all of the pentachlorophenol contaminant present in the soil if the EASW process merely caused a phase transfer of the contaminants from the soil phase to the wash-water phase. But analysis of the effluent wash-wastewater showed that it contained only 22.7% of the PCP originally present in the contaminated soil. This means that nearly 77% of the pentachlorophenol was apparently chemically destroyed by the EASW process. The pH of the effluent water was 10.

The results from the pentachlorophenol contaminated soil-washing tests of the BioTrol Soil Washing system developed by BioTrol Inc. [6] were compared with the EASW results in Table 5. It was found that: (1) the removal efficiencies reported for the BioTrol system were below 90%, unlike the EASW process where the removal efficiencies were frequently above 99%, (2) though the removal efficiencies based on the washed soil of the output were reported to be 89% for the BioTrol soil-washing tests, the total output of the process contained significant amounts of pentachlorophenol in the coarse oversize, fine oversize, the fine particle cake and the dewatering effluent. The EASW process, on the other hand, generates only one effluent water phase containing the pentachlorophenol contaminant. Also, more than two-thirds of the pentachlorophenol contaminant originally present in the feed soil is apparently destroyed or modified through chemical oxidation in the EASW process.

Table 5  
EASW vs. the BioTrol system

	EASW	BioTrol <sup>a</sup>
Removal efficiency %	99.2	87
<i>Pentachlorophenol – percent of total output</i>		
Dewatering effluent	23	34
Coarse oversize	0	24
Fine oversize	0	5
Fine particle cake	0	27

<sup>a</sup> Obtained from a SITE program demonstration of one configuration of soil-washing process developed by BioTrol Inc.

## 5. Conclusions

The EASW process can successfully reduce petroleum and chlorinated hydrocarbon contamination to acceptable levels for soils that contain a very high percentage of clay and silt (EPA Regime III). Moreover, the contaminated wastewater generated in the process appears to be treatable by standard biological treatment methods. Analysis of the effluent water from the EASW indicated that this process is not merely transferring the contaminants from the soil phase to the water phase, but that it also promotes chemical oxidation and mineralization of the hydrocarbons. Based on these tests, the EASW process was found to be superior to other soil-washing processes and remediation technologies in three areas: (1) it addresses contamination of fine-grained materials whose enormous surface area per unit volume of bulk soil precludes treatment by many technologies; (2) it has a source of both mechanical and chemical energy that is more effective than many conventional washing processes; and (3) it minimizes the dispersal of clays and thereby reduces the loss of fine soil particles in the process-wash-wastewater that is normally associated with soil-washing processes.

## Acknowledgements

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