



## **ELECTROREMEDIATION OF SOILS CONTAMINATED WITH HEXAVALENT CHROMIUM: BENCH – SCALE STUDIES**

**Rajeev Kumar, Kali Sanjay, GP Bajpai and R. Shekhar**

*Department of Materials and Metallurgical Engineering, Indian Institute of Technology,  
Kanpur 208 016, India*

### **ABSTRACT**

Soil contamination is serious environmental problem all over the world. A number of industrial activities, including coal-fired power production, electroplating, leather tanning, timber treatment, pulp production and mineral ore and petroleum refining, generate solid and aqueous waste products that are enriched with various heavy metals including Hexavalent chromium [Cr(VI)]. Cr(VI) is carcinogenic in nature. Electroremediation is emerging as a viable, cost effective in-situ technique for cleaning heavy metal contaminated soils. The objective of this study has been to determine the optimum parameters for energy-efficient electro remediation of Cr (VI) for use under real life conditions. Therefore, experiment was carried out in 1-D and Bench-Scale. Bench-Scale experiments have been carried out with Cr (VI) - contaminated Kanpur soil, containing 500mg Cr (VI)/kg soil in a 1 m square tank. The operating parameters were taken as follows: (i) Constant voltage: 50V, 75V & 100V (ii) The moisture content in soil: 18% and 40% (iii) Flushing (complete replacement of anode chamber liquid with fresh tap water) interval: flushing every 4 hours and 8 hours. Experiments suggest that best condition for energy-efficient electro remediation is Voltage 50V, moisture content in soil 40 %, anode chamber pH 8.2 and flushing frequency every 4 hours. Maximum 82% chromium was recovered from regular Kanpur soil.

**Key words:** *Electroremediation, Hexavalent Chromium.*

### **1. INTRODUCTION**

Soil contaminated with Cr (VI) due to Industrial wastage, Chemical industries, Tanneries, Distilleries etc. there are several In-situ & Ex-situ techniques. Electroremediation is emerging as a viable, cost-effective technique for cleaning heavy metal contaminated soils. Unfortunately, issues related to the application of electro remediation to real-life problems have not been adequately addressed. So first time in IIT Kanpur took first step on it & have done more efficient work. Primarily 1-D experiments carried on soils contaminated with Cr(VI) have showed that the technique is highly effective and the efficiency of the process significantly depends on the type of soil and then after it is implemented on field scale.

The major objective of this paper is to study the effect of moisture, and flushing interval on kinetics of electro remediation and consequently identify the 'optimum moisture and flushing time' from different point of views like percent removed, energy efficiency and impact of soil properties on remediation efficiency.

## 2. EXPERIMENTAL

### 2.1 1-d setup:

A cylindrical Perspex tube, 15.25 cm long and 3.81 cm in diameter, was used to house the contaminated soil. Two Perspex caps containing porous graphite electrodes and liquid chambers, with provision for gas venting, were screwed on to both ends of the Perspex cylinder. The soil was separated from the electrodes by intervening electrolyte chambers. The soil, in turn, was supported by porous canvas cloth and filter paper. The ends of the two Perspex caps were connected to two reservoirs, which served as an “electrolyte source” for electroosmosis. Four dummy electrodes were inserted in the soil to determine the voltage distribution along the length of the cylinder. Fig. 1 shows the details of the experimental setup.

### 2.2 bench-scale:

Figs. 2 & 3 show the experimental setup of the bench scale experiment. Experiments were conducted in 1m X 1m X 0.254 m tank. 70 kg Cr (VI) contaminated soil was used in each experiment. Cr (VI) was taken in the form of potassium dichromate crystal ( $K_2Cr_2O_7$ ). Potassium dichromate crystal was mixed thoroughly in tap water upto desired concentration level and then mixed with soil to the desired saturation. 16 porous tubes were taken. Porous tubes (Diameter: 5 cm, length: 14 cm, Thickness: 1 cm, Volume: 250ml) containing graphite-electrodes were placed in the soil at specified spaces interval as shown in Fig 3.1 & 3.2.

Dummy electrodes, made of Kanthal wire, were inserted in the soil to determine the potential distribution in soil, Dummy electrodes were connected with a Data Acquisition System (DAS). DAS was used for automatically storing the voltage gradient value, at different section of soil, with the help of dummy electrode in specified time. Current consumption was measured with the help of a manual multimeter.

## 3. EXPERIMENTAL PROCEDURE

The whole experimental operation is divided in further sections

Fabrication of porous tubes

Soil preparation and compaction

Measurement of current, voltage & Data acquisition system(DAS)

Sampling

Soil decontamination

Analysis

The tubes should be porous and pores should be small such that ions can pass through the tube. At the same time pores should not allow the water to flow out of the tube due to hydraulic gradient.

The soil was mixed thoroughly with the requisite volume of Cr (VI) solution to achieve the desired Cr (VI) concentration of 500 mg/kg in Muller. After mixing, the soil was poured in the tank. Table1 shows the Initial properties of the compacted soil slurries spiked with  $K_2Cr_2O_7$  used in a typical electro remediation experiment.

During the course of the experiments, the level in the reservoir connected to the (i) negative reservoir increased, and (ii) the positive reservoir decreased due to electro osmotic flow. The levels in the reservoirs were continuously adjusted. At regular intervals, (i) samples were drawn from the electrode reservoirs and chamber for Cr analysis and (ii) voltage drop in different sections of the soil and current were monitored.

Significant amount of Cr (VI) was present in soil in end of each experiment. Dumping of this contaminated soil would cause environmental problems and risk to human health. So, the decontamination of soil was carried out in 100-litre stirrer system. After that ferrous sulphate was added in bucket for reducing Cr (VI) to Cr (III) and then slurry was flushed out.

Cr (VI) was analyzed calorimetrically using a UV double beam spectrophotometer in accordance with US-EPA method 7197A. For total chromium analysis, the electrode chamber solution was mixed with a few drops of 1:1 nitric acid heated at 50°C to dissolve precipitates, if any. The resulting solution was oxidized with ammonium persulphate in the presence of silver nitrate, and analyzed for Cr (VI).

#### 4. RESULTS AND DISCUSSION

Remediation efficiency may be defined as the ratio between Cr removed to initial Cr in the soil. Experiments were carried on different operating parameters and conditions. Which is shown in Table-2. Where as different electrode configuration pointed as A & B, which is shown in Fig. 3(a) & 3 (b) respectively.

##### 4.1 base case:

Fig. 4 shows the percentage of Cr removed into the anode chamber. Accumulation of Cr in the anode chamber suggests that electro migration is the principal mechanism for the transport of Cr (VI) in the base case experiment.

##### 4.2 effect of moisture:

Fig. 5 shows the kinetics comparison with base case percentage of Cr removed into the anode chamber.

##### 4.3 effect of voltage:

At 75 volt: Fig. 6 shows the percentage of Cr removed into the anode chamber.

(ii) At 100 volt: Fig. 7 shows the percentage of Cr removed into the anode chamber.

##### 4.4 effect of concentration:

Fig. 8 shows the kinetics comparison with base case percentage of Cr removed into the anode chamber.

#### 5. SPECIFIC POWER CONSUMPTION

Energy efficiency will be determined in terms of specific energy consumption, which is defined as:

$$\text{SEC} = \text{Specific energy consumption} = \frac{\text{Total Energy consumed (watt - hour)}}{\text{Percentage of chromium removed}}$$

#### 6. CONCLUDING REMARKS:

Electroremediation experiments conducted on Kanpur soil under different applied voltages gave an insight into the operating conditions such as effect of applied potential, optimal time period and power consumption.

Results of bench scale experiment showed:

1. Cr (VI) contaminated Kanpur soil on bench scale is cleaned predominantly by electro migration but if flushing interval not maintain properly then diffusion also come into existence and affect the removal rate.
  2. The best operating condition for Cr (VI) contaminated Kanpur soil on bench scale is to operate with 50 V, pH 8.2, soil moisture content 40 %, with flushing every 4 hours.
  3. Significant amount of chromium (15-35 %) is adsorbed in Kanpur soil on bench scale.
- Reduction of hexavalent to trivalent chromium takes place due to presence of reducing agent and also due to high moisture. Because high moisture tends hydrolysis and by hydrolysis reaction reduction is favored without presence of any reducing agent only electric field is required for that.

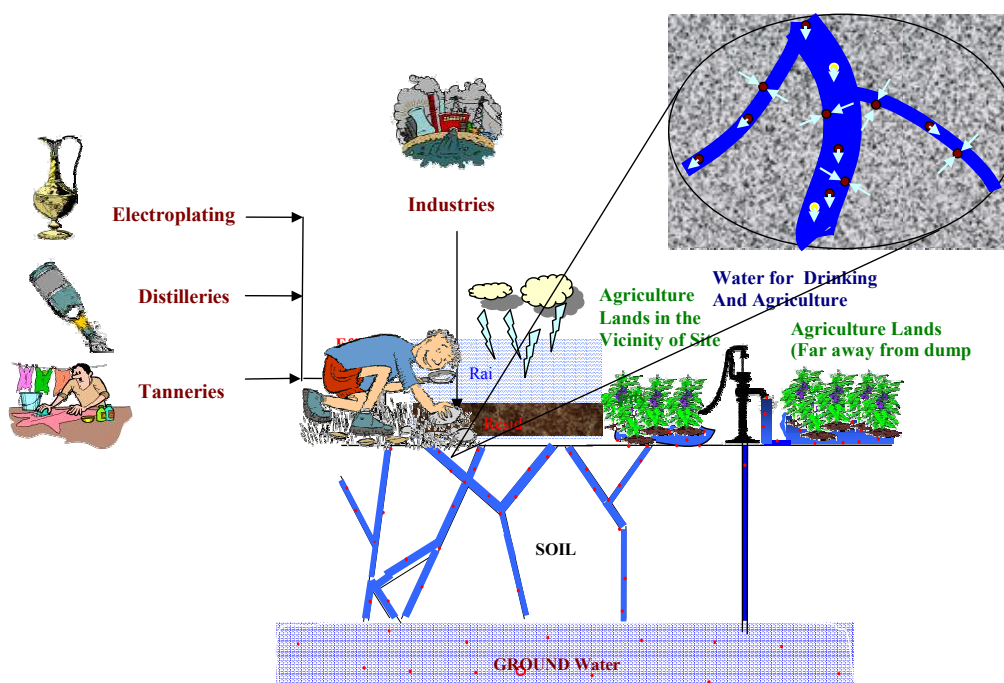
## TABLES

Table-1 Physical properties of Kanpur soil

Physical parameters	Values
Compacted soil Porosity	48-49 %
Loose soil porosity	58-60 %
pH	8.2
Bulk density	1.38 gm/cm <sup>3</sup>
Moisture content percent	18 & 40

Table-2 Experiments carried on different operating parameters

Operating Parameters	Base case	Experiments carried on different Operating Conditions			
Voltage/current	50V	50V	75V	100V	50V
Moisture	18	40	18	18	40
Flushing frequency (hrs)	4	4	8	8	4
Anode Fluid	Tap water	Tap water	Tap water	Tap water	Tap water
Soil Taken	Kanpur Soil	Kanpur Soil	Kanpur Soil	Kanpur Soil	Kanpur Soil
Concentration (mg/Kg)	500	500	500	500	100
Electrode configuration	A See fig 3(a)	A	B See Fig 3 (b)	B	A



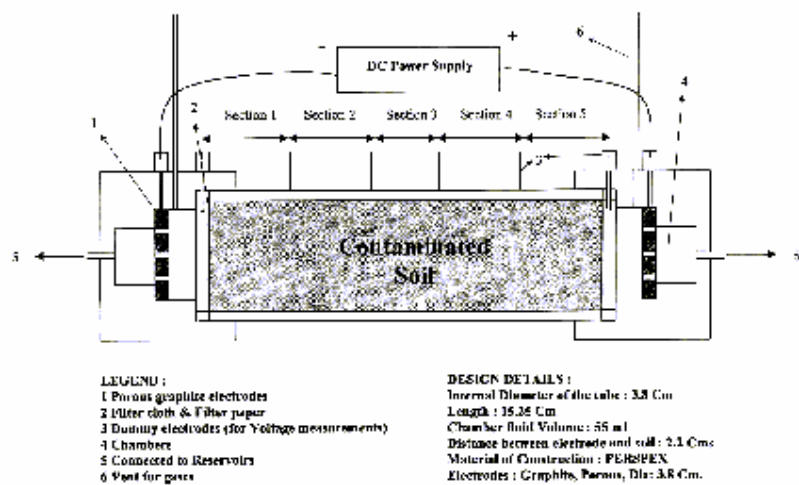


Fig.1 Schematic representation of 1-D experiment.

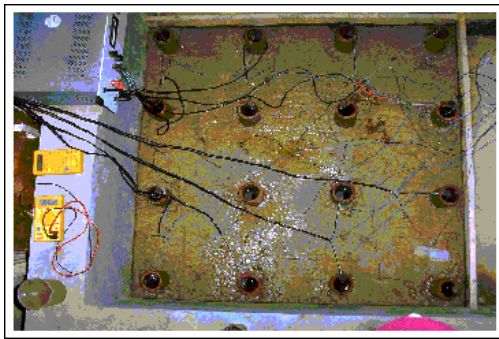


Fig 2. Experimental setup of Bench scale

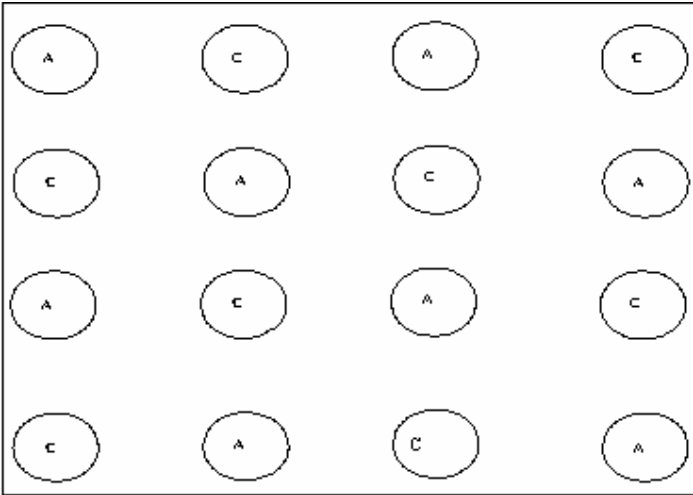


Fig 3(a) Schematic diagram of Experimental setup (Base case)

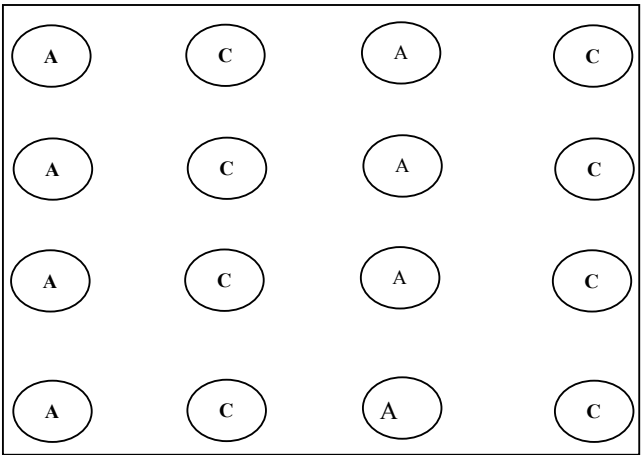


Fig 3(b) Schematic diagram of Experimental setup

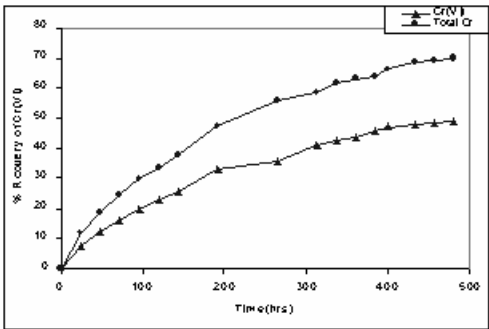


Fig 4 Kinetics of base case experiment.

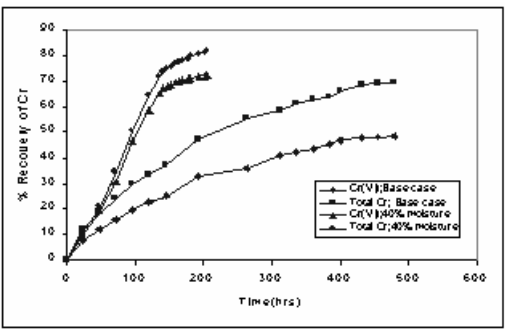


Fig 5 Kinetics comparison of 40% moisture percent with base case.

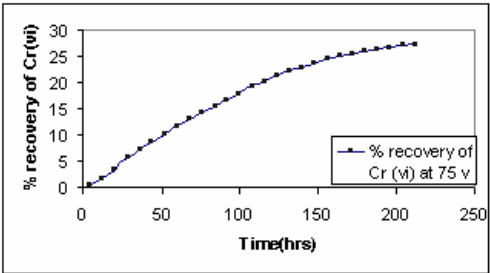


Fig. 6 Kinetics of Cr removal at 75-volt

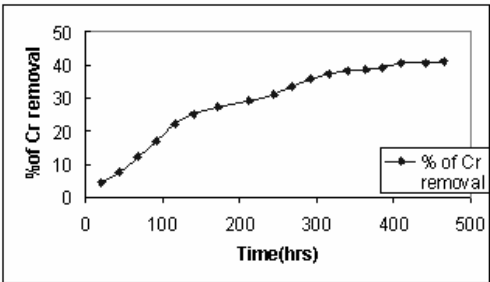


Fig.7 Kinetics of Cr removal at 100 V

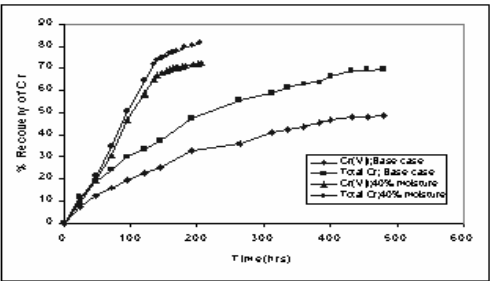


Fig. 8 Kinetics comparison of 100ppm Concentration percent with base case.

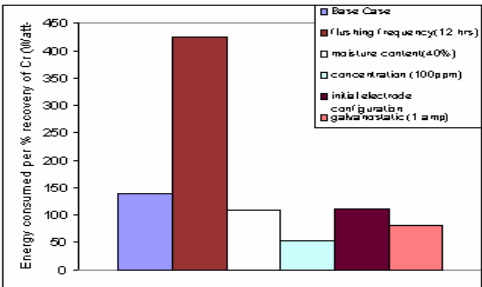


Fig. 9 shows the SEC comparison with base case