



## Effects from different types of construction refuse in the soil on electrochemical remediation

Lisbeth M. Ottosen<sup>a,\*</sup>, Thomas Eriksson<sup>a</sup>,  
Henrik K. Hansen<sup>a</sup>, Alexandra B. Ribeiro<sup>b</sup>

<sup>a</sup> Department of Civil Engineering, Building 204, Technical University of Denmark, 2800 Lyngby, Denmark

<sup>b</sup> Department of Environmental Sciences and Engineering, Faculty of Sciences and Technology,  
New University of Lisbon, Quinta da Torre, P-2829-516 Caparica, Portugal

Received 28 August 2001; received in revised form 29 October 2001; accepted 11 December 2001

### Abstract

At abandoned industrial sites some of the previous buildings are often left behind. If the soil at such site is polluted with heavy metals and is to be remediated by an electrochemical method, the construction refuse within the soil matrix will influence the remediation action. The influence of different sorts of construction refuse on electrochemical soil remediation was investigated in laboratory cells. An insulator, a stone, resulted in an uneven Cu removal in the close vicinity of the stone itself. An electrically conductive screw disturbed the Cu removal due to the redox reactions occurring at the surface of the screw causing pH changes in the soil. Two types of refuse with ionic conducting properties were placed within the test cell, a piece of brick and concrete. The brick did not influence the Cu removal from the soil to a high extent, but it was seen that during the remediation the Cu concentration in the brick itself increased. In the case of concrete the Cu mobilized from the soil was simply found to adsorb very strongly to the concrete and thus the Cu could not be removed from the soil and the concrete as a whole. Furthermore, the removal of Cu in the soil next to the concrete was quite poor. It is very important to be aware of the presence of construction refuse at such sites when planning an electrochemical remediation action. All the refuse types investigated here influenced the Cu removal negatively compared to the reference experiment. © 2002 Elsevier Science B.V. All rights reserved.

*Keywords:* Electrochemical soil remediation; Copper; Construction refuse; Electrokinetics

### 1. Introduction

Sites that have been polluted from previous industrial activities contain often various types of construction refuse. The refuse can be found within the soil matrix and if the

\* Corresponding author. Fax: +45-45-88-59-35.  
E-mail address: lo@byg.dtu.dk (L.M. Ottosen).

site is to be remediated by an electrochemical method, where an applied electric field is the cleaning agent, the construction refuse will affect the electric field and thus the remediation.

Geokinetics from The Netherlands did several in situ experiments in the late 1980s and experienced that one of the remediation actions had a higher energy demand than estimated due to metal objects that had been left in the soil [1]. The electric field lines had passed the metallic objects and bypassed the polluted soil matrix and thus the soil was not remediated as expected in the part area with the metal objects. Later Lageman from geokinetics advised that metal objects >10 cm should be removed from the soil whenever possible before the remediation action because of the interference with the electric current [2]. Examples of metallic construction refuse at abandoned industrial sites are water tubes, reinforcing rods and tins.

It is not only metallic pieces with electron conducting properties that will influence an electrochemical remediation. Other types of construction refuse can be expected to do so, too. Large electrically insulating objects, such as e.g. plastic barrels or large stones can affect the electric field and so can different porous pieces of e.g. wood, bricks or concrete with ionic conducting properties.

The present paper investigates the influence of different sorts of construction refuse on electrochemical remediation. In the soil of laboratory remediation experiments a stone, a screw, a piece of concrete or a piece of a brick was placed. These objects were chosen to cover examples of refuse with insulating properties, electron conducting properties and ionic conducting properties.

## 2. Electrodialytic soil remediation

Different electrochemical soil remediation methods have been developed and the present paper deals with the electrochemical soil remediation. In this method the soil is placed in a desalination compartment of an electrochemical cell instead of the normal electrolyte solution to be desalted [3–5]. The principle of a three-compartment laboratory cell for electrochemical soil remediation is shown in Fig. 1. Between the soil and the anolyte an anion exchange membrane is placed and between the soil and the catholyte a cation exchange membrane is placed. This use of ion exchange membranes means that the products from the electrode processes will not enter the soil. In the case of inert electrodes, where  $\text{OH}^-$  ions are produced at the cathode, the cation exchange membrane prevents the  $\text{OH}^-$  ions from entering the soil, thus hindering development of an alkaline zone in the soil in the cathode end. An alkaline zone would decrease the mobility of most heavy metals markedly. It is often beneficial to

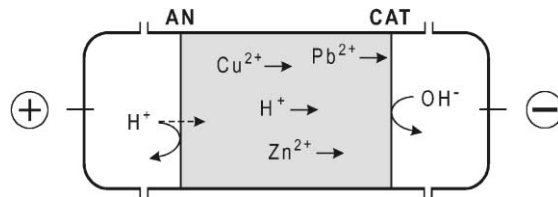


Fig. 1. The principle of electrochemical remediation (AN: anion exchange membrane, CAT: cation exchange membrane).

maintain an acidic environment in the catholyte to prevent membrane fouling and this is maintained by addition of acid. The cation exchange membrane also prevents the anions from the acid to enter the soil.

Even when an anion exchange membrane is placed between the anolyte and the soil as shown in Fig. 1, the soil is acidified during the remediation process. It is likely that this acidification is due to water splitting ( $\text{H}_2\text{O} \rightarrow \text{H}^+ + \text{OH}^-$ ) at the anion exchange membrane where the hydroxyl ion will enter the anode compartment and the hydrogen ion will enter the soil due to the applied electric field [4]. Due to the developing acidic front in the soil from the anode side the heavy metals will desorb and thus be mobile in the electric field. The ion exchange membranes ensure that the electric current is not wasted in carrying current from the electrode compartments through the soil. The current is carried by ions from the soil into the electrode compartments and the  $\text{H}^+$  ions from the water splitting at the anion exchange membrane. Thus, there is no competition in the soil between easily mobile ions from the anolyte and the ions originating from the soil.

Using the ion exchange membranes for separating the soil from the solutions in the electrode compartments means that the choice of process solution will not affect the soil properties. Thus, it is possible to optimize the choice of these solutions so reuse of the heavy metals is possible. After the remediation the heavy metals that were removed as cations and anions will be found concentrated in the catholyte and the in the anolyte, respectively. The pollutant of the actual study is Cu and this heavy metal can be electroprecipitated from the processing solution at the cathode as metallic Cu and reused for industrial purposes [6].

### 3. Construction refuse and electric properties

#### 3.1. Concrete

Concrete is one of the most versatile and widely used construction material. The basic constituents of most structural concrete are a coarse aggregate, a fine aggregate or sand, cement and water. When the concrete is produced the cement will react with water and form different sorts of calcium silicates and calcium hydroxide. About 25–50% of the cement paste is  $\text{Ca}(\text{OH})_2$  and thus the pH of the concrete is high, in general between 12 and 14. Under normal conditions concrete has a high durability, but no cementitious material can withstand lengthy exposure to acids, particularly to inorganic acids. The concrete is damaged due to leaching of calcium hydroxide from the cement paste when exposed to inorganic acids [7].

The electric conductive property of concrete has been suggested used for removal of chloride ions to minimize corrosion as early as in 1976 [8]. DePaoli et al. [9] showed that electrokinetics has potential for removing Ce, Sr, U and Co from crushed concrete when using enhancement solutions of a high pH.

#### 3.2. Brick

The raw material in building brick production is clay. Brick production occurs at temperatures about 1000 °C. The aim of the heat is to cause localized melting (sintering) of

the clay, which increases strength and decreases the soluble salt content without loss of shape of the clay unit. The main constituents of the clay, silica and alumina, do not melt and they are merely fused together by the lower melting point minerals, such as metallic oxides and lime [10]. This process changes the original clay characteristics. Ceramic building materials, such as bricks offer good resistance against aggressive media [11]. The porosity of building bricks is about 20–40% [11]. When a brick is placed in a soil matrix to be remediated by an electrochemical method, the electric current can pass the brick due to the porous structure.

### 3.3. Stone

A stone is an insulating object and thus the current cannot pass it. This means that the electric field lines must pass in the soil next to the stone. The field lines will thus be closer in the soil in a cross-section with the stone than in a cross-section without the stone, everything else equal.

### 3.4. Screw

A screw of stainless steel has a low electric resistance compared to the soil and thus the electric field tends to pass the screw and bypass the soil to some extent. In the screw the current is carried by electrons whereas in the soil ions are charge carriers and this means that, at the end of the screw pointing at the anode, reduction processes can be expected to occur, e.g. metal precipitation or electrolysis of water. In the other end of the screw pointing at the cathode, oxidizing processes are expected to occur. This may be electrolysis of water or the screw may corrode due to the oxidation of  $\text{Fe}^0$  to  $\text{Fe}^{2+}$  or  $\text{Fe}^{3+}$  in this end of the screw.

## 4. Experimental section

### 4.1. Analytical methods

The concentration of the elements were measured after pretreatment of the soil as described in Danish Standard 259 Determination of metals in water, sludge and sediments, general guidelines for determination by atomic absorption spectrophotometry. The 1.0 g of dry soil and 20.0 ml (1:1)  $\text{HNO}_3$  were heated at 200 kPa (120 °C) for 30 min. The liquid was separated from the solid particles by vacuum through a 0.45  $\mu\text{m}$  filter and diluted to 100 ml. The elements were measured by AAS. The units used in this paper are mg/kg dry matter.

Soil pH was measured by mixing 10.0 g dry soil and 25 ml 1.0 M KCl. After 1 h of contact time pH was measured using a radiometer pH electrode. At the end of the experiments with concrete and brick, these pieces of construction refuse were washed carefully by hand in water to remove soil particles. The pieces were cut into slices and crushed to a finegrained material by hand in a mortar. In each of these slices Cu concentration and pH was measured by the same methods as the soil analysis.

Table 1  
Some characteristics of the experimental soil, the concrete and the brick that were used in the experiments 2 and 3

	Soil	Concrete	Brick
Cu concentration (Danish Standard 259) (mg/kg)	680–830	13	4.4
pH (1:2.5; soil:1 M KCl)	5.9	12.1	8.8
Organic content (loss on ignition at 550 °C) (%)	2.2		
Carbonate content (volumetric calcimeter method) (%) [12]	0.2		
Clay (<0.002 mm) (%)	5		
Silt (0.002–0.06 mm)(%)	21		
Sand (0.06–2.0 mm) (%)	72		

#### 4.2. Experimental soil

The experimental soil was sampled at a wood preservation site and it was polluted by Cu and As. This investigation only covers Cu. Some characteristics of the experimental soil are given in Table 1.

#### 4.3. Laboratory equipment

The electrochemical remediation experiments were made in laboratory cells as the one shown in Fig. 1. The cells were made with glass and had an i.d. of 8 cm. The ion exchange membranes were obtained from Ionics (Anion exchange membrane AR204 SZRA B02249C and cation exchange membrane CR67HUY N12116B). In each electrode compartment, 0.01 M NaNO<sub>3</sub> with pH adjusted to about two with HNO<sub>3</sub> was circulated. Platinum coated electrodes from Bergsoë AC, Denmark, were used as working electrodes and a power supply (Hewlett–Packard E3612A) was used to maintain a constant current.

#### 4.4. Electrochemical remediation experiments

Five remediation experiments were made with soil from the same batch. Four experiments were made where a piece of construction refuse placed in the soil: concrete, brick, screw or stone. A reference experiment without any construction refuse was made, too. The cylinder for the soil compartment was filled by hand. Each piece of construction refuse was placed in the middle of a cross-section of the soil cylinder. In Table 2 some experimental data are

Table 2  
Parameters of the construction refuse, the length of the soil compartment, current and duration for the five experiments

Refuse	Length refuse (cm)	Diameter refuse (cm)	Weight refuse (g)	Refuse distance form AN (cm)	Soil compartment (cm)	Current (mA)	Duration (days)	Cu concentration (mg/kg)
–	–	–	–	–	15	10	34	910
Concrete	2.5	6	120	9	15	10	31	680
Brick	2.5	6	112	9	15	10	32	680
Screw	7.2	1	47	4.8	15	10	35	830
Stone	0.6–1.2	5–7	61	4	15	10	33	830

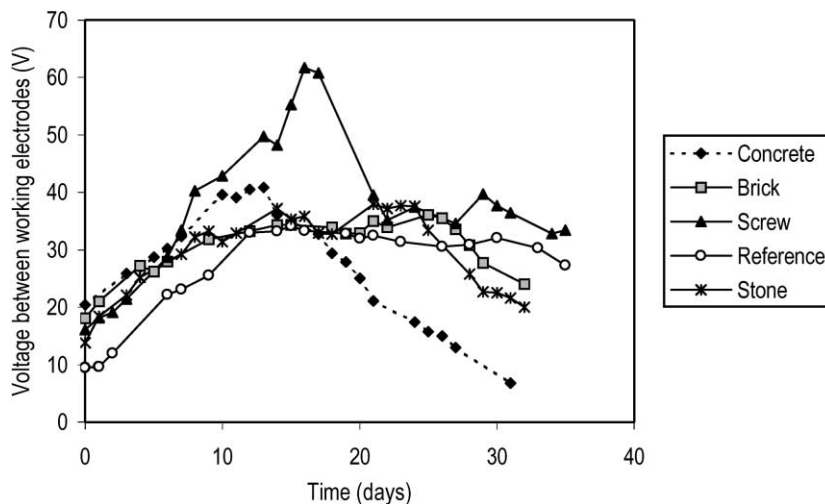


Fig. 2. The variation in voltage between the working electrodes in the five experiments.

given about the size and placement of the refuse. In Table 2 the current and the duration of the five experiments are given. The initial concentration of Cu in the soil was measured for each experiment and these concentrations are given in Table 2.

When the experiments were finished the soil was segmented into six slices and each slice was separated into two parts: an inner cylinder with the diameter of 4–6 cm and the outer ring around this cylinder. In experiments 2 and 3 the concrete and the brick, respectively, were the inner cylinder of the fourth slice. After drying each soil sample was mortared by hand and carefully mixed. Triple determination of the Cu concentration in the soil was made in both the inner cylinder and the outer ring. Double determination of soil pH was made. The concrete cylinder and the brick cylinder were cut into four slices each of 0.6 cm thick.

## 5. Results

The five experiments were performed with a constant dc current of 10 mA (corresponding to the current density  $0.2 \text{ mA/cm}^2$ ). The development of the voltage between the working electrodes during the experiments is shown in Fig. 2.

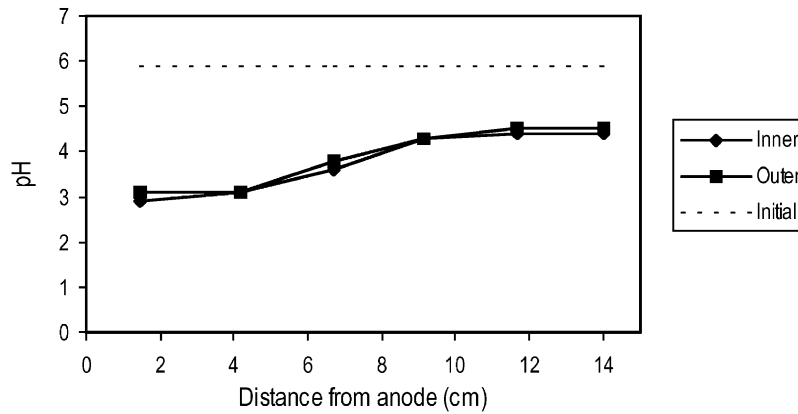
The pH profiles in the soil at the end of the experiments are shown in Fig. 3A–E. In Fig. 3B and C the pH profiles in the concrete and in the brick is shown, too. In Fig. 4A–E the corresponding Cu concentration profiles are given.

## 6. Discussion

### 6.1. Variation of overall voltage in the experiments

Experiences with electrodynamic soil remediation experiments performed with soil from the actual site have showed that the voltage generally follows the same pattern. An increase

## A. Reference experiment



## B. Concrete

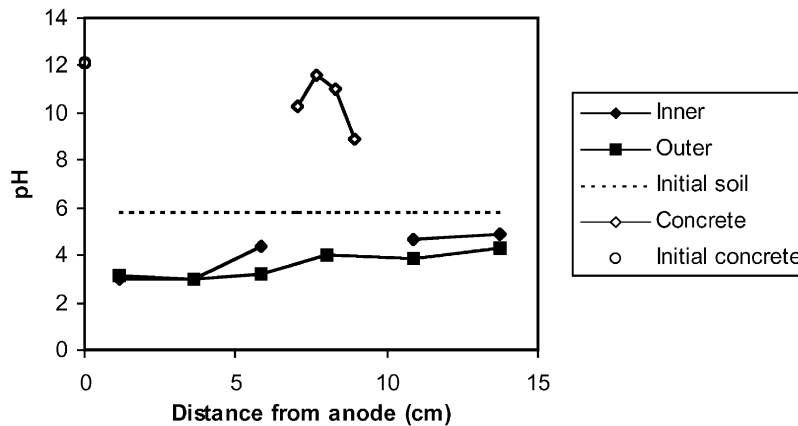


Fig. 3. The pH profiles in the soil from anode towards cathode.

in voltage during the first days is seen and then the voltage stabilizes at a voltage dependent on the applied current. When the current density is  $0.2 \text{ mA/cm}^2$ , as in the experiments reported here, the voltage stabilizes at approximately 30–35 V for about 30 days [3] and if the current density is  $0.3 \text{ mA/cm}^2$  the voltage stabilizes at about 55 V for about 25 days [4]. After this period of a quite stable level the voltage starts to decrease and reaches finally a quite low level of about 5 V and this is at the time, where the acidic front has passed all through the soil volume [4].

The experiments were performed with a dc current and thus the variations in voltage can be related directly to variations in resistivity between the working electrodes. The voltage over time of the reference experiment, Fig. 2 developed as expected from the earlier experiences described above and stabilized after some days at a level of about 32 V. The pattern of the voltage in the experiments with the stone and the brick were quite similar

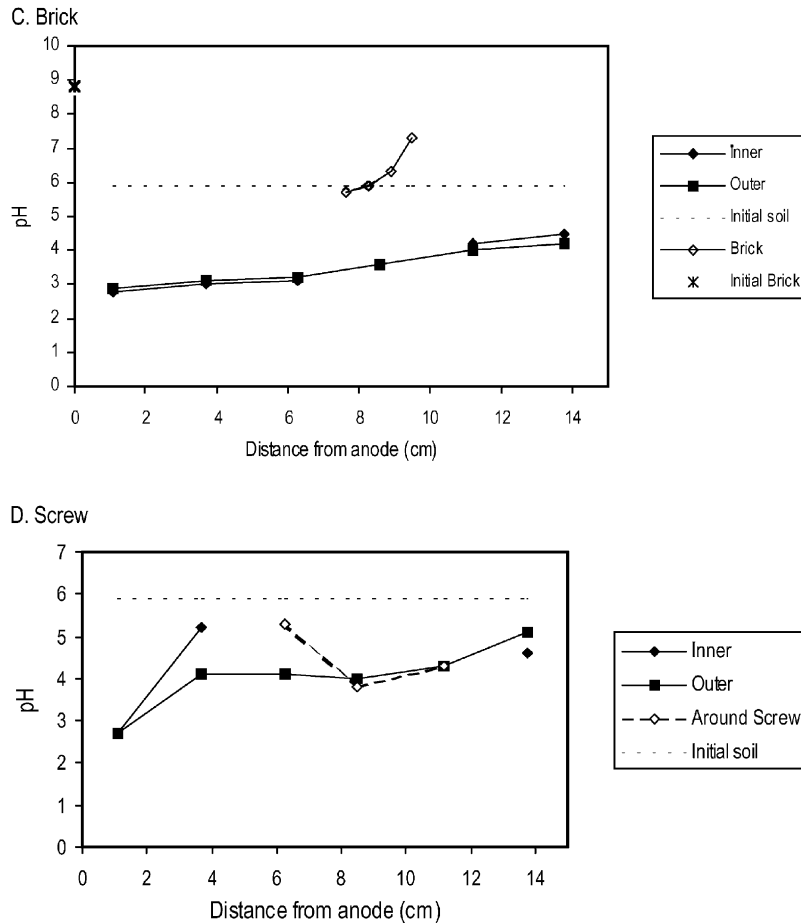


Fig. 3. (Continued).

to the reference experiment. This means that neither the brick nor the stone are markedly influencing the resistivity in the soil as total. In the experiment with the screw the voltage increased during a longer period of time than the voltage in the other experiments and reached almost the double value of 62 V in a few days and after this the voltage drops and stabilizes at a level similar to the others. The increase in voltage to the high level indicates that there are areas in the cell where the resistivity is high compared to the other experiments and this is probably related to the processes occurring at the ends of the screw, which are discussed in Section 6.2. In the experiment with the concrete the voltage develops as in the other experiment initially but then a decrease was seen after about 15 days. This means that the presence of the concrete in the soil decreases the overall resistivity of the cell compared to the others and this may be due to the dissolving of the concrete releasing free ions.



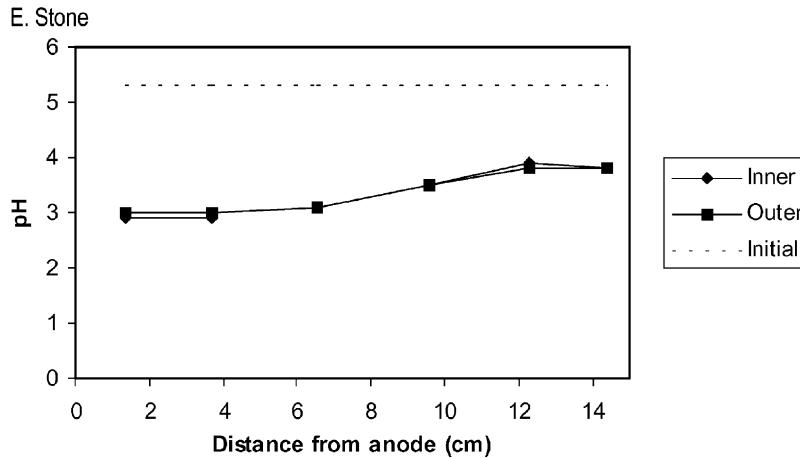


Fig. 3. (Continued).

### 6.2. Development of acidic front in the soil

The variation of the double determination of soil pH, which was made on each soil slice, did not exceed 0.1 pH unit in any case.

From Fig. 3A it can be seen that in the reference experiment the pH profile has equal shapes in the inner part of the soil cylinder and the outer part, but there seems to be a tendency for the pH to be slightly lower in the inner part of the soil than in the outer part. The pH was decreased all through the cell but only in the first two slices the final level of 2.9–3.0 is reached. During the acidification of the soil, Cu is desorbed and removed by the electric current and from earlier experiences it is seen, that when pH reaches the level of about three in the soil, the remediation is finished [4].

The pH profile in the soil in the inner and the outer part of the slices developed differently in experiment 2 with the concrete, see Fig. 3B. In the outer part of the soil the pH profile had developed like in the reference experiment, even with a slightly lower pH in slice 3 compared to the reference experiment, but in the inner part of the soil pH is higher in the slices next to the concrete. The acidic pore water in the soil was influenced from the highly alkaline pore water in the concrete and vice-versa. When the soil around the concrete was acidified,  $\text{Ca}(\text{OH})_2$  in the concrete could be expected to decompose. This decomposition would buffer the development of the acidic front in the concrete and thus the pH of the concrete was still high at the end of the experiment. Meanwhile the pH was lowered in the concrete compared to the initial pH, see Fig. 3B and especially in the two outer slices of the concrete the pH decrease is evident. In the concrete slice closest to the cathode pH was decreased from about 12 to 8.9.

The decomposition of  $\text{Ca}(\text{OH})_2$  may be the reason for the lower resistance in the soil in this experiment.  $\text{Ca}^{2+}$  is an important cationic charge carrier and this element is carried all through the soil when first mobilized. This was shown in the case where the  $\text{Ca}^{2+}$  ions originated from decomposition of calcareous parts in the soil itself [13]. After 14 days of

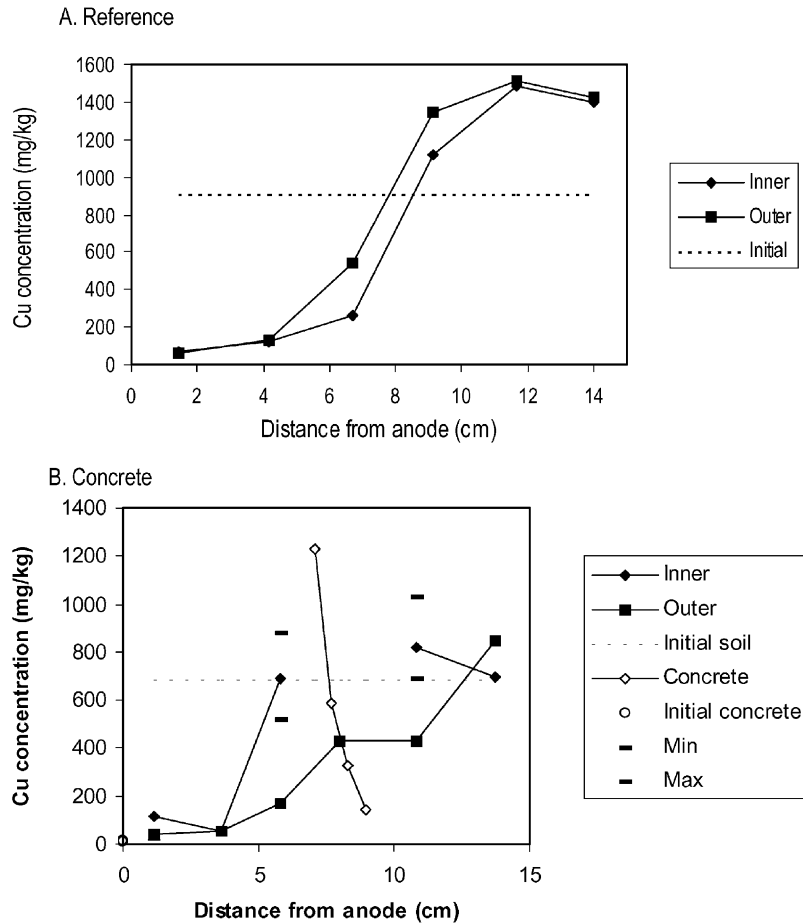


Fig. 4. Cu concentration profiles in the soil from anode towards cathode.

current the voltage started to decrease in experiment 2 and this was not the case in the reference experiment. In it was shown that the resistivity of the soil was closely connected to the developing acidic front [4]. The resistivity of each soil slice decreased to a very low level when the acidic front had passed the slice, probably because of the increased number of free ions in the acidified soil origination from dissolution and desorption processes. The decrease in experiment 2 may start at the time where the acidic front reaches the concrete and the  $\text{Ca}^{2+}$  ions from the concrete starts to be an important charge carrier in the soil between the concrete and the catholyte.

In experiment 3 a brick was placed in the soil and the pH profiles in the inner part and in the outer part of the soil developed equally, see Fig. 3C. The pH profiles were similar to the reference experiment and the outer soil in experiment 2 with the concrete. The brick did not influence the overall voltage of the cell, probably because the brick did not influence the

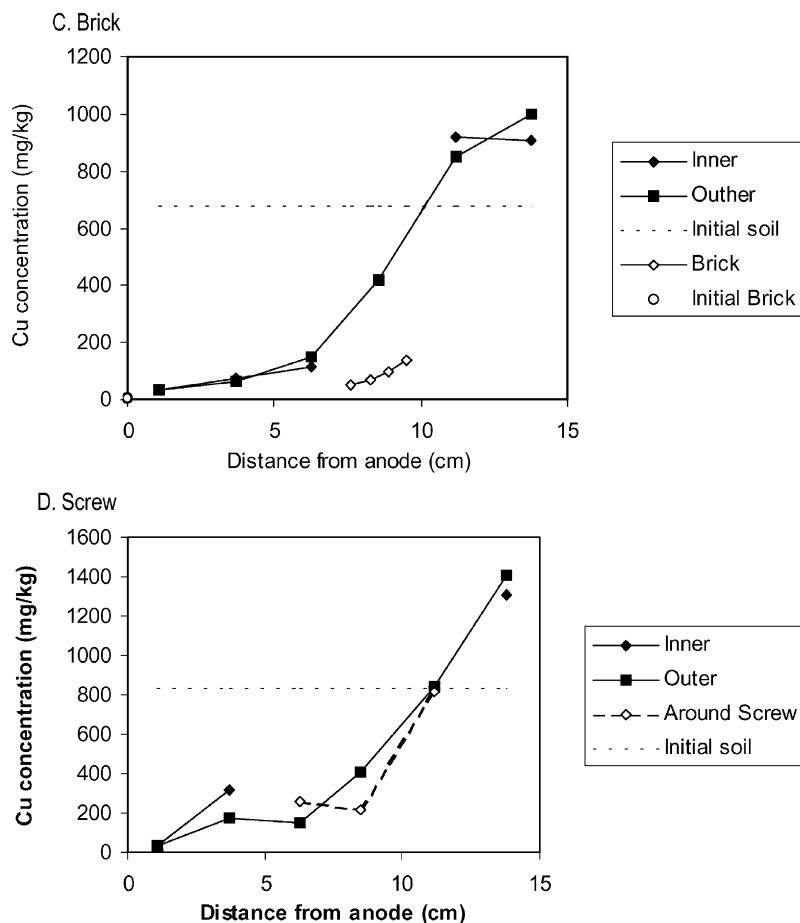


Fig. 4. (Continued).

development of the acidic front in the soil. The pH decreased all through the brick itself, but pH of the brick was still at least two pH units higher than in the soil around it.

Fig. 3D shows the soil pH profiles in experiment 4, where the refuse in the soil was a screw. In the soil closest to the anode the final pH was 2.9, i.e. in the same level as the other experiments, but the pH in slice 2 was 5.3 and that is higher than in the other experiments where pH in slice 2 was around 3. Slice 2 was the slice in front of the screw in the direction of the anode. This high pH is due to the cathodic electrolysis of water at this end of the screw resulting in a release of  $\text{OH}^-$  to the soil and thus the developing acidic front is buffered here. The other end of the screw pointing at the cathode was seen corroded, probably due to the oxidation of  $\text{Fe}^0$ – $\text{Fe}^{2+}$  or  $\text{Fe}^{3+}$  in this end of the screw. The soil pH of the inner part of the soil between the screw and the cathode was lowered even though the development of the acidic front from the anion exchange membrane was buffered at the other end of the

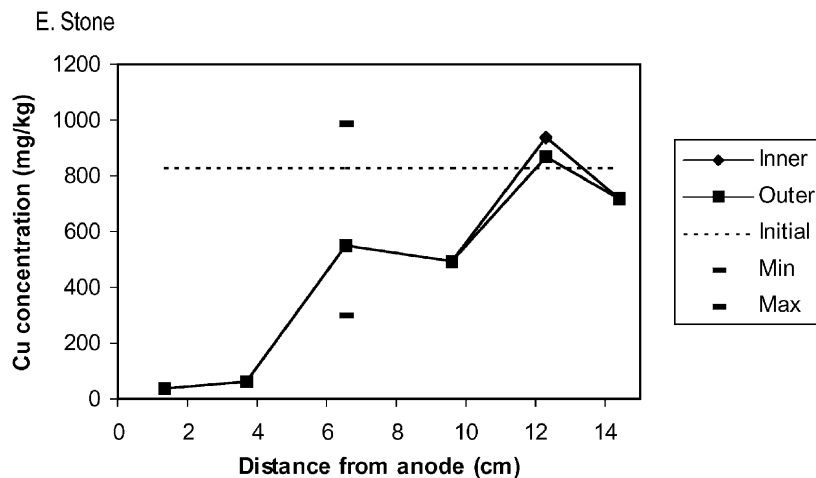


Fig. 4. (Continued).

screw and pH in the soil next to the screw was lowered, too. This may be an indication that electrolysis of water occurred here, too. The higher voltage in this experiment can be due to both the  $\text{OH}^-$  production at the end of the screw pointing at the anode neutralizing the acidic front developing from the anion exchange membrane and the voltage can also be influenced by the release of iron ions that, together with different anions, can form precipitates in the soil pores closing these.

In experiment 5 where the stone was placed in the soil, the developing acidic front was, as expected, not influenced markedly by the stone. There is a tendency for the pH in the soil around the stone to be lower than in the reference experiment and this may indicate that the current density has been higher here due to the stone.

### 6.3. Removal of Cu

The removal of Cu from a soil in an applied electric field is well known to be highly pH dependent, see e.g. [4]. When the soil is acidified Cu will desorb from the soil particles to free  $\text{Cu}^{2+}$  ions in the soil solution and these ions are then moved towards the cathode by electromigration.

For all soil slices the Cu concentration was made as triple determination. In the following figures, showing Cu concentration profiles for the five experiments, error bars are shown, when the variation between these three measurements exceeded 50 mg/kg. When the variation was < 50 mg/kg the mean value is shown, only.

In experiment 1, the reference experiment, it is seen that there is a difference in the Cu profiles in the inner cylinder of the soil and the ring around it, Fig. 4A. In the first two slices the concentrations are the same but, then in the next two slices, the Cu profile has proceeded further in the inner part of the soil than in the outer and this may indicate that the current density is not equally distributed over the cross area of the soil, even though there are

electrolyte solutions between the soil and the metallic electrodes, where the current density most often is expected to be equalized over the membrane area. The current density was higher in the center of the soil between the electrodes. Meanwhile, it was shown in other experiments that all soil volume can be remediated and thus the low concentration is also reached in the outer part of the soil, but this experiment indicated that the remediation of the outer part was delayed compared to the inner soil [3]. The indication that pH was lower in the inner part of the soil than in the outer part confirms this observation.

The Cu profiles in the soil is highly affected by the concrete in experiment 2, see Fig. 4B. The Cu profiles in the soil are related to the pH profiles from Fig. 3B when looking at the mean values. In the first two slices where pH was decreased the Cu concentration was decreased, too. Next to the concrete pH was higher in the inner cylinder than in the outer and this was the case for the Cu concentration, too. The variation in Cu concentration next to the concrete was high compared to the other samples. The error bars are shown for these two slices, but not for the others, since the variation did not exceed 50 mg Cu/kg here. The variation of pH in the two slices next to the concrete was not higher than for the other samples, i.e. < 0.1 units. The pH measurements for a homogenized sample are less sensitive to variations than the measurements of Cu concentration. Cu accumulated within the concrete matrix. In the concrete slice closest to the anode the Cu concentration was increased from 13 to 1230 mg/kg and it is possible that some of the Cu in this concrete slice is attached to the surface of the concrete, but the Cu has moved within the concrete, too, since Cu concentration was increased in all parts of the concrete compared to the initial values. The Cu concentration in the concrete drops rapidly in the direction towards the cathode so the Cu is adsorbed to a high extent when first entering the concrete. Most of the Cu mobilized from the first part of the soil is accumulated in the concrete in this experiment.

In the brick the Cu concentration increased during the experiment, too, see Fig. 4C. The initial concentration in the brick was measured to about 4.4 and at the end of the experiment the concentration was between 50 and 140 mg Cu/kg. The Cu concentration in the brick increased in the direction towards the cathode and this corresponds well to pH in the brick (Fig. 3C), but it is in contrast to the Cu profile in the concrete. It seems as if the Cu ions were current carrier in the brick as in the soil around it and the Cu was not adsorbed in the brick.

Comparing Fig. 4A and D it is evident that the screw influenced the Cu removal in the soil. The screw caused the Cu concentration to be higher in the end pointing towards the anode, but at the same time, the concentration was lower in the soil next to the screw. The Cu profile corresponds quite well to the pH profile in this experiment as in the other experiments.

In experiment 5 it is clearly seen from the error bar in slice 3 that the stone had indeed disturbed the Cu removal in this slice. The error bar shows the highest concentration and the lowest concentration measured in the slice with the stone. The Cu removal was almost evenly distributed in the other slices in the outer and the inner parts. Thus, it is a rather local phenomenon where the Cu removal was disturbed by the stone. Since the stone was tilted it was not possible to take samples in front of and behind the stone, but the very high variation in concentration in exactly this slice (a variation that have not been seen in any other slice of the experiments reported here) may indicate that the stone can have caused areas where the current was not passing with the same intensity as in the others. The remediation was

only half finished when the experiment was ended and thus it cannot be seen whether the areas next to the stone would be remediated either, but with a delayed effect from the stone.

## 7. Conclusion

The different forms of construction refuse were shown to influence the Cu removal in the experiments performed. In the experiments the soil was segmented into slices and each slice was separated in an outer and an inner part. In the reference experiment with soil without construction refuse it was found that the inner part of the soil was remediated slightly faster than the outer part, so the removal did not proceed evenly even in a homogenized soil sample. Never the less there is no doubt that the construction refuse influenced the remediation. Concrete: Cu was highly adsorbed in the concrete and the high pH of the concrete itself buffered the acidic front developing in the soil, decreasing the removal rate of Cu in the soil next to the concrete, too. Brick: It was evident that the electric field passed the brick since Cu was transported through it, but the disturbance of the Cu removal was much less than in the case of concrete, since Cu was not adsorbed in the brick to nearly the same extent. Screw: The electric field were found to pass the screw which means that oxidation occurred in the end of the screw pointing at the cathode and reduction reactions occurred in the other end. As a result of these processes, the soil pH was influenced markedly by the presence of the screw and soil pH has not decreased next to the screw pointing at the anode, whereas pH decreased next to the screw and next to the end pointing at the cathode. The Cu removal was thus poorer in the anode end and slightly better in the cathode end, when comparing the results with the reference experiment. Stone: In the presence of the stone in the soil the variation of Cu concentration in the slice containing the stone was very high compared to the other slices and to the other experiments reported here. This may indicate that the unevenly distributed electric field lines close to the stone will influence the Cu removal and decrease the removal rate markedly in some areas. All the four types of construction refuse thus either delayed or inhibited the Cu removal compared to the reference experiment. Presence of construction refuse within a soil volume to be remediated by an electrochemical method, should prior to the remediation always lead to an evaluation of the influence from the refuse on the remediation, so the refuse can be removed from the soil if necessary.

## Acknowledgements

AS Bioteknisk Jordrens SOILRENS is acknowledged for their cooperation and financial support.

## References

- [1] R. Lageman, *Chemistry & Industry*, September 1989, p. 585.
- [2] R. Lageman, *Environ. Sci. Technol.* 27 (1993) 2648.
- [3] L.M. Ottosen, H.K. Hansen, S. Laursen, A. Villumsen, *Environ. Sci. Technol.* 31 (1997) 1711.
- [4] L.M. Ottosen, H.K. Hansen, C.B. Hansen, *J. Appl. Electrochem.* 30 (11) (2000) 1199.

- [5] H.K. Hansen, L.M. Ottosen, B.K. Kliem, A. Villumsen, *J. Chem. Technol. Biotechnol.* 70 (1997) 67.
- [6] L. Hansen, Treatment of aqueous solutions polluted with heavy metals in connection with electro-dialytic soil remediation. Ph.D. Thesis, Technical University of Denmark, Denmark, 2000.
- [7] M.S. Eglinton, *Concrete and its Chemical Behaviour*, Thomas, Springfield, 1987.
- [8] J.E. Slater, D.R. Lankard, P.J. Moreland, *Mater. Perform.* 15 (1976) 21.
- [9] D.W. Depaoli, M.T. Harris, I.L. Morgan, M.R. Ally, *Sep. Sci. Technol.* 32 (1/4) (1997) 387.
- [10] G.D. Taylor, *Construction Materials*, Longman, New York, 1991.
- [11] D. Knöfel, *Corrosion of building materials*, Van Nostrand Reinhold, New York, 1978.
- [12] R.H. Loeppert, D.L. Suarez, in: *Methods of Soil Analysis. Part 3. Chemical Methods-SSSA Book Series no. 5*, 1996, p. 451.
- [13] L.M. Ottosen, A. Villumsen, H.K. Hansen, A.B. Ribeiro, P.E. Jensen, A.J. Pedersen, *Electrochemical Soil Remediation: Accelerated Weathering?* in: *Proceedings of the Presentation of Paper 5 in EREM 2001 of 3rd Symposium and Status Report on Electrokinetic Remediation*.