

Electroremediation of a soil contaminated by lead from a battery manufactory effluents

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Accepted 14 November 2004

ABSTRACT

Electrokinetic remediation has been tested to remove lead from an Algerian contaminated soil sited near a battery plant. High level of lead content ($4432 \pm 275 \mu\text{g/g}$) mainly causes a pollution of the zone area which is sited nearby an agricultural land. A sequential chemical extraction procedure has shown that up to 71% of the total lead is found bounded to the mineral surfaces symbolised by Fe – Mn oxides. The precipitation of hydroxides observed during the electroremediation with pure water is owed to its electrolysis and it represents a handicap to the process. The use of acetic acid and EDTA to prevent this phenomenon has been studied by means of voltage measurements along the specimen. Prospective experiments were carried out during a fixed period (240 hours) to conclude by a long duration test of 1012 hours with 0.1M EDTA in the catholyte and 0.2M of sodium hydroxide in the anolyte. The voltage has been maintained constant to correspond to electric field strength of 1V/cm. In these conditions, it has been possible to remove up to 76.0% of the total lead content. © 2005 SDU. All rights reserved.

Keywords: Remediation; Lead; Electrolysis; EDTA; Acetic acid

1. INTRODUCTION

Soil contamination became a concerned problem giving rise to many laboratory studies in recent years. It is due to the fact that various phenomena and numerous factors can intervene as pollutants provoking serious dangers to the human health. Heavy metals are generated from the factors which are the most difficult to eliminate. Despite the fact that processes adapted to organic compounds are varied, those that treat heavy metals are underdeveloped. The techniques used as stabilization - solidification (Conner, 1994) or soils washing method (Pruijn and Groenendijk, 1993) are not efficient. On the other hand, containment methods as low permeability barriers (Diependaal *et al.*, 1993) were used, but they have shown that the contaminant can diffuse again after a certain period of time.

Excavation is also a form of decontamination but it has several associated costs, and generates a discharge problem. Recently, two soil decontamination techniques were subjected to several laboratory experiments: soil washing and electrokinetic remediation. Montero *et al.* (1994) tested acid leaching for heavy metals removal using various inorganic acids such as HCl, H₂SO₄ and HNO₃. Results were encouraging in some cases, however, soil fertility risks being decreased by the corrosive effect of acids. Complexing agents have been used as leaching reagents by Elliott and Brown (1989) to remove lead and by Fisher *et al.* (1993) to treat soils containing various metals as pollutants. The greatest amount of chemical extractions was performed only at the laboratory scale, however, an in situ decontamination by means of cadmium acid extraction has been applied in the Netherlands (Urlings *et al.*, 1988).

Electrokinetic soil remediation is another in situ process that has been recently developed. It is also called either electro-dialytic or electroosmosis, and it combines the technique of electro-dialysis with electromigration of ions in the contaminated soil. The theoretical fundamentals of this technique are explained in papers elaborated by Acar (1992) and Acar and Alshwabkeh (1993) where a review of the main research in this field has been reported (Acar, 1992). On the other hand, Sikdar *et al.* (1998) have presented a critical review of the membrane use in the electroremediation of contaminated soils.

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Lageman *et al.* (1989) have used the electrokinetic extraction to remove successfully arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, molybdenum, nickel, lead, antimony and zinc from several porous media such as peat, clay and fine argillaceous sand. The removal of anionic contaminants like fluorine (Costarramone *et al.*, 1998; Pomes *et al.*, 1999) and nitrate (Eid *et al.*, 2000) by electroremediation is reported and the technique has been also applied to the radionuclides (Acar and Alshwabkeh, 1993, Harris *et al.*, 1997, Schwartz *et al.*, 1997; Yu and Neretnieks, 1997) and organic compounds (Probststein and Hicks, 1993; Röhrs *et al.*, 2002).

However, the physico-chemical soil-contaminant interactions that occur simultaneously during the process may limit the efficiency of contaminant transport (Yeung *et al.*, 1997). In effect, in many cases, the water dissociation near the electrodes produces both H⁺ and OH⁻ ions. The increase of hydroxyl production can give rise to hydroxides precipitates in some cases. To prevent this phenomenon and enhance the decontamination, ion exchange membranes were used by Hansen *et al.* (1997) and Ottosen *et al.* (1997). In laboratory experiments, Hansen *et al.* (1997) have shown that the reduction of the soil pollutant by means of electrodiolytic remediation depends upon the soil pH, lime content and the speciation of the heavy metals. This process appears to be very promising, however it should be optimized to each soil type and pollution. This fact shows that the soil remediation cannot give rise to a general process. Apart from the membrane use to enhance the electrokinetic process, organic acid can be added near the cathode to neutralize the OH⁻ produced by water dissociation and complexing agent can also be used to facilitate the metal desorption from the contaminated soil.

In this paper, the electrokinetic remediation of an Algerian soil contaminated by lead is studied. The contaminant results from a battery manufactory located at 12km in the east of Algiers near an agricultural area. It is confirmed that lead constitutes a specific risk (Mushak, 2003) to human health and it can degrade cultivable soils. Two routes have been examined to enhance the electrokinetic process: the use of acetic acid and disodium salt of ethylenediaminetetraacetic acid. Voltage measurements are performed to show the electric field strength variation inside the soil for each case studied.

2. EXPERIMENTAL

Typical samples of contaminated soil were taken near an industrial waste site located at 12km in the east of Algiers. On the Table 1, physico-chemical properties of the studied samples are reported. All experiments were performed using air-dried soil grains with size <2mm, excepting for both the moisture content and the ignition loss measurements. The soil pH is measured in KCl solution (1M) at a liquid/solid ratio of 2.5 using a Jenway 3045 Ion Analyser. Moisture content and ignition loss are determined after keeping the soil at 378K and 823K temperatures respectively. The active calcareous is analyzed using Bernard calcimeter. The cation exchange capacity (C.E.C.) is determined by the acetate ammonia method and the organic matter is calculated using the potassium dichromate oxidation. Lead analyses are performed using a Varian AA110 atomic absorption spectrophotometer. To determine the mineralogical forms of the solids, X-ray diffraction analysis of the soil is carried out using Phillips-PW1710. All chemicals used are of analytical grade.

Table 1
Physico-chemical properties of the contaminated soil

Parameter	Data
pH (KCl)	7.30 ± 0.02
Moisture Content (%)	17.4 ± 0.6
Ignition Loss at 550°C (%)	5.0 ± 0.9
Active calcareous (%)	4.9 ± 0.7
C.E.C. (meq/100g)	4.82 ± 0.17
Organic matter (%)	1.26 ± 0.11
Lead (µg.g ⁻¹)	4432 ± 275
Nickel (µg.g ⁻¹)	109 ± 13
Cadmium (µg.g ⁻¹)	12 ± 8
Quartz (%)	45.0
Calcite (%)	24.5
Dolomite (%)	1.6
Gypse (%)	1.4
Albite (%)	8.3
Chlorite (%)	7.3
Kaolinite (%)	6.3
Illite (%)	2.1
Orthoclase (%)	3.2

In order to assess the mobility of the contaminants, sequential chemical extractions are carried out. This speciation can provide valuable information on the association modes of metals as reported by Reddy *et al.* (2001) in the case of electrokinetic extraction of metals from a polluted sandy soil and by Ribeiro and Mexia (1997) in partitioning of copper at the completion of electrokinetic tests. The adopted procedure follows closely the scheme proposed by Tessier *et al.* (1979). Table 2 shows the speciation of lead in the different geochemical fractions. Lead is mainly adsorbed on the mineral surfaces. More than 71% of the total concentration is present in the metal bounded Fe–Mn fraction, 9.50% of lead is bounded to carbonates and hence could be altered by pH change. Finally, 15.33% of initial lead is present in the residual fraction, which might be difficult to remove.

Table 2
Speciation of lead in the different geochemical fractions of the soil

Fraction	Lead ($\mu\text{g/g}$)
F ₁ : Exchangeable	41
F ₂ : Carbonates – bounded	428
F ₃ : Fe-Mn oxides bounded	3211
F ₄ : Organic matter bounded	135
F ₅ : Residual	691
$\sum F_i$ (i=1,5)	4506
Total metal content	4432

Electrokinetic tests were carried out in a cylindrical Teflon cell which is represented on the Figure 1. The central compartment (length = 12.5cm, inner diameter = 2.5cm) containing the specimen is separated from cathodic and anodic sides by a filter paper (Whatman N°5) inserted between a grid of rigid nylon (mesh size = 2mm). The circulation of the catholyte and the anolyte is ensured by a peristaltic pump (Watson Marlow 313S) from graduated reservoirs (250ml each) at a flow rate of 15 ml.mn⁻¹ which allows the escape of generated gas near the electrodes. In the two extremities there are two metallic electrodes (platinum - coated titanium sheets). A weighed amount (90.0 \pm 2.0g) of the soil is put in the central compartment and saturated with deionized water. The resulting specimen has average moisture content of 17.0 \pm 0.5%. The applied voltage is delivered by a power supply (Consort E802) and maintained constant in all the runs at a value of 15.5 V corresponding to an electric field strength of 1V/cm. The voltage across the cell is measured by means of platinum wire (diameter = 1mm) connected to a multimeter and inserted at a depth of 3 mm of the soil, using the cathode as a reference.

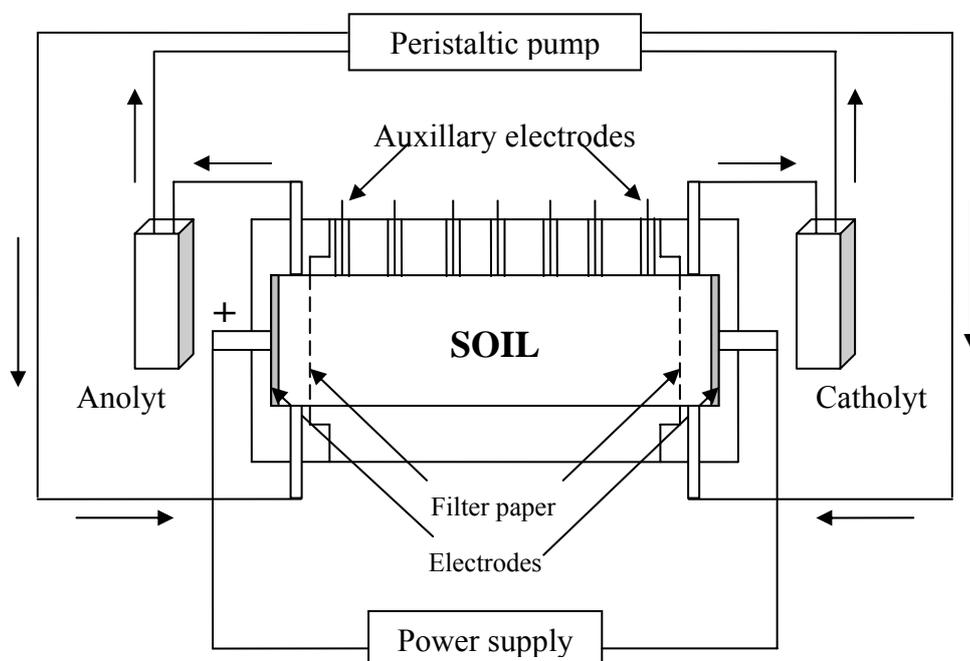


Figure 1. Scheme of the experimental cell

The operating conditions are reported on the Table 3. A period of 240 h is fixed arbitrarily, since this duration is expected to give useful information when optimal operating conditions are used. After each run, the soil specimen is sliced into 7 sections and air – dried before performing metal analysis and pH measurement. All experiments have been performed two times for each corresponding set of operating conditions.

Table 3
 Operating conditions of electrokinetic experiments

Run designation	Catholyte composition	Anolyte composition	Duration (hours)
Unenhanced test	H ₂ O	H ₂ O	240
Acetic acid enhanced test	CH ₃ COOH (3.5<pH<4.0)	H ₂ O	240
	CH ₃ COOH (3.0<pH<3.5)	H ₂ O	240
	CH ₃ COOH (2.5<pH<3.0)	H ₂ O	240
EDTA enhanced test	EDTA (0.05 M)	NaOH (0.20 M)	240
	EDTA (0.10 M)	NaOH (0.20 M)	240
	EDTA (0.20 M)	NaOH (0.20 M)	240
	EDTA (0.10 M)	NaOH (0.20 M)	1012

3. RESULTS AND DISCUSSION

3.1. Electrokinetic tests in water medium

Electrokinetic tests were carried out using some samples of contaminated soil mixed with deionized water. The quantity of water has been fixed to simulate the initial average moisture content of the soil. Experiments were performed during 240 hours and the Figure 2 shows the pH change inside both anolyte and catholyte compartments. After 100 hours, it is noticed that the pH decreases and remains below 2.5 in the anolyte while it increases and reaches a value of 11.5 in the catholyte.

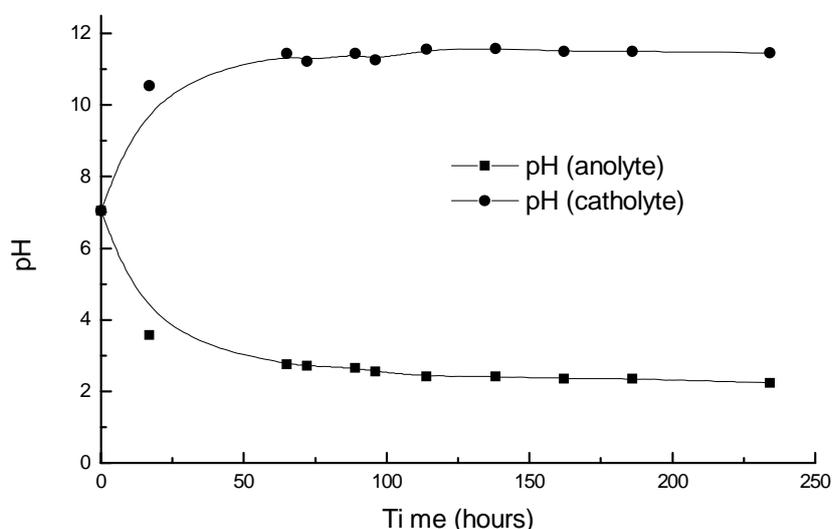


Figure 2. pH variation as a function of time inside both the anolyte and catholyte compartments

The voltage measurement in various distances from the cathode has also shown an increase as a function of time (Figure 3). It increases particularly near the anode. In the early stages of the processing, the voltage gradient does not exceed 0.2V/cm in the whole sample but it attains 1.8V/cm near the anode after 240 hours showing two different slopes in the graphs. On the other hand, a part of lead can be adsorbed by the soil again after a short moving according to the speciation found.

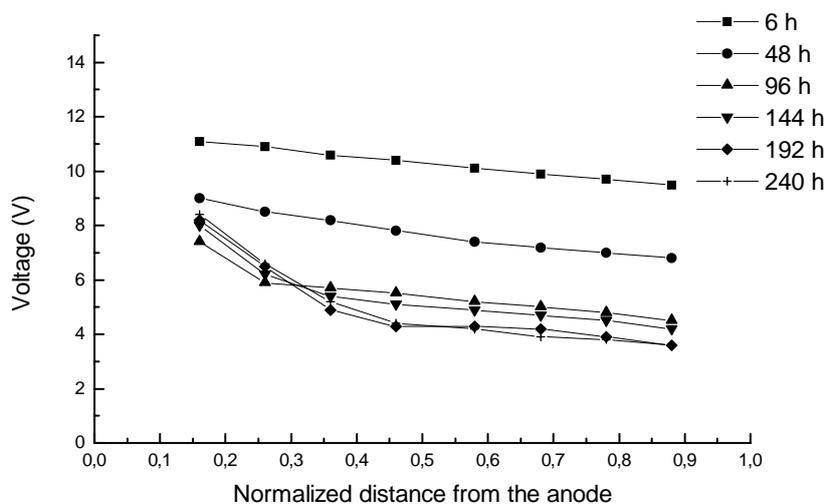


Figure 3. Evolution of the ddp from the cathode as a function of time for electrokinetic remediation using pure water

The electrical current variation is also followed and it is reported on the Figure 4. It is noticed that the current decreases after 72 hours to be stable at 0.40 mA for the rest of the experiment.

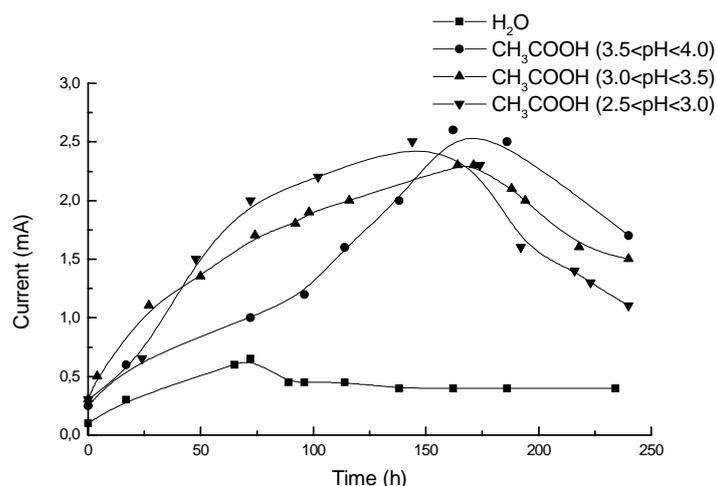


Figure 4. Current variation as a function of time for electrokinetic remediation using both pure water and acetic acid

The distribution of lead is very slightly altered after the application of the electric field as it is shown on the Table 4. Only 8.6 and 12.5% of lead is removed from the sections adjacent to the anode and the most of lead is found accumulated in the middle of the cell (sections 3-4) and in the section 7 near the cathode. This result confirms that the precipitation of hydroxides which occurs reduces dramatically the lead mobility.

Table 4

Lead distribution between the electrodes after 240hours of electroremediation in pure water and with adding acetic acid (Run 1 : H₂O, 240 h; run 2 : CH₃COOH, 3.5<pH<4.0, 240 h; run 3 : CH₃COOH, 3.0<pH<3.5, 240 h; run 4 : CH₃COOH, 2.5<pH<3.5, 240 h)

Run number	1	2	3	4
Anode (mg)	0.00	0.00	0.00	0.00
Anolyte (mg)	0.12	1.02	0.94	1.18
Filter paper (mg)	0.20	0.34	0.35	0.20
Section 1 (mg.g ⁻¹)	4.16	4.08	3.97	3.78
Section 2 (mg.g ⁻¹)	3.98	4.06	3.78	3.43
Section 3 (mg.g ⁻¹)	4.93	3.26	3.47	3.31
Section 4 (mg.g ⁻¹)	4.87	3.66	4.20	3.97
Section 5 (mg.g ⁻¹)	4.24	5.31	4.84	4.42
Section 6 (mg.g ⁻¹)	4.57	5.44	3.83	4.23
Section 7 (mg.g ⁻¹)	5.02	2.93	3.04	3.01
Filter paper (mg)	0.35	1.32	0.87	1.02
Catholyte (mg)	9.28	17.43	18.83	24.16
Cathode (mg)	0.48	11.46	19.02	25.28
Total lead (mg)	418.71	401.47	389.20	388.44
Initial lead (mg)	409.50	414.05	412.23	407.23

Thus, it appears that all investigations should be oriented towards the avoiding of hydroxide formation. For this purpose, two ways are envisaged:

- The use of a weak acid as it has been suggested by Puppala *et al.* (1997)
- The use of a complexing agent which can dissolve the hydroxides and gives a greater mobility to lead through the contaminated soil towards the electric voltage.

3.2 Influence of acetic acid on the soil electroremediation

Puppala *et al.* (1997) have tested the use of acetic acid for the treatment of some synthetic samples of soils composed by a mixture of clays spiked with lead. They have shown that the process will be longer and it will require more energy expenditure and a higher cost of the remediation. They have obtained good yields of metal extraction with a pH level of 5-6 but they recommend to decrease the catholyte pH level less than 4 to increase them. On the other hand, Jordan *et al.* (1997) have observed the enhancement of the lead mobility in the presence of dissolved natural organic matter. In this work, the speciation performed in the natural studied soil has shown that lead is mainly adsorbed on mineral surfaces, then, it can represent a good example for testing again acetic acid. This acid was chosen because the relative high solubility of most acetate combined to the proton production which neutralize the cathodic electrolysis product. This set of experiments involves the use of acetic acid solutions in the catholyte with pH ranging between 2.5 and 4.0 as it has been recommended by Puppala *et al.* (1997). The catholyte pH was controlled periodically and maintained at its initial value by adding a few drops of acetic acid.

The current increases as a function of the acetic acid concentration until 170 hours of the experiment duration (Figure 4) and it decreases after. In all acetic acid enhanced experiments, the current intensity is high compared to the previous experiments.

The voltage variation in different soil locations at regular intervals of time is reported on the Figures 5a, 5b and 5c. When the catholyte pH is ranged between 3.5 and 4.0 (Figure 5a), the electrical potential gradient increases until 96 hours of processing. When this time is reached, the potential gradient value is around 0.60V/cm in the part of the cell near the anode and 0.80V/cm in the other part. After 96 hours, it decreases and does not exceed a value of 0.2V/cm.

For tests concerning the use of acetic acid at pH between 3.0-3.5 and 2.5-3.0 (Figures 5b and 5c respectively), the voltage reaches its maximum after a duration of 96 hours. The corresponding value of the electrical gradient potential is then 0.65 and 0.50V/cm for runs number 3 and 4 respectively. It is noticed a decrease of the voltage for a period ranging between 144 to 196 hours. This variation is nearly the same at this period as the current value decreases.

A neutral pH is observed in the whole soil sample at the end of the experiments (Figure 6) and there is no alkaline region near the cathode as it was found for the electroremediation with pure water. However, this soil pH is not sufficient to carry an efficient extraction of lead species.

For all the acetic acid enhanced electrokinetic tests, lead transport occurs from the anode to the cathode as suggested by the data reported in Table 4. For these experiments, lead extraction ratios are increasing when moving away from the anode until section 3 where they are equal to 28.4, 23.7 and 27.3% for runs number 2,3 and 4 respectively. In sections 4, 5 and 6, the metal is accumulated with an extent decreasing, as the catholyte pH becomes more acid. Whatever the concentration of CH_3COOH used, around 35.6% of lead is extracted from the zone near the cathode. The removed lead is found in the catholyte or electrodeposited at the cathode. The best removal yields for this set are obtained for a catholyte pH less than 3, but the residual concentration of lead in the whole specimen is still high and exceeds the mean value of 3.74mg/g.

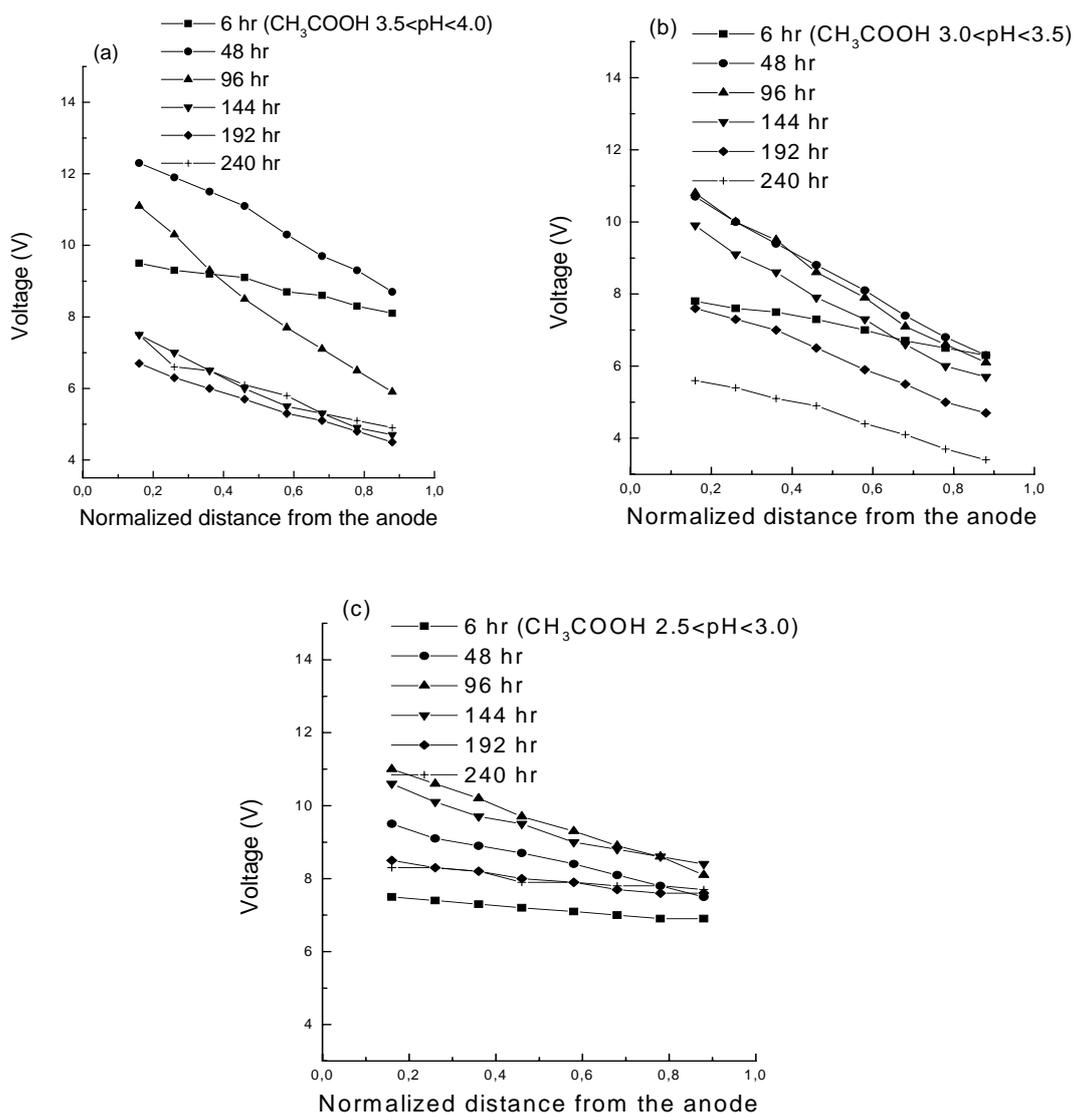


Figure 5. Evolution of the ddp from the cathode as a function of time for electrokinetic remediation using acetic acid at various pH

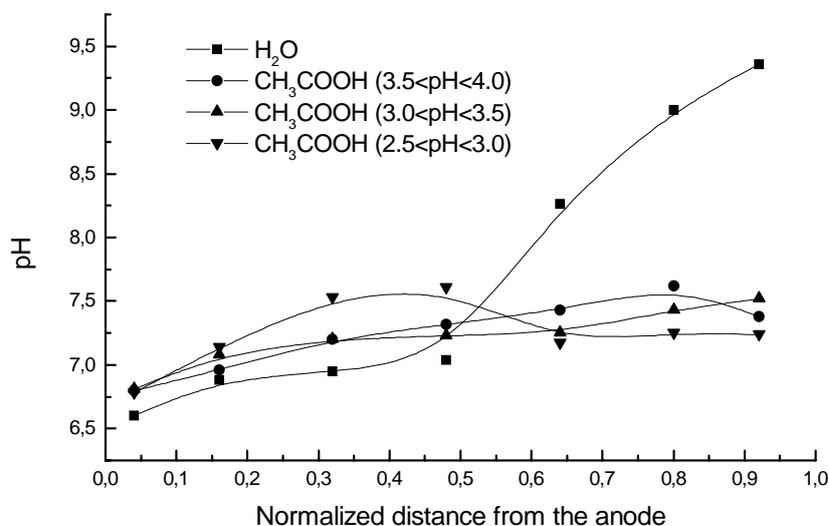


Figure 6. pH values inside the soil at the end of experiments using both pure water and acetic acid

3.3. Influence of EDTA on the soil electroremediation

The third part of experiments deals with the use of a chelating reagent to desorb the species of interest and prevent the hydroxides formation inside the soil. In effect, the EDTA as a ligand can compete efficiently the hydroxyl ion in any interaction with lead species. It is used for this purpose at concentrations ranging between 0.05 and 0.20M. According to Wong *et al.* (1997), it was found that the concentration of the ligand should be at least five times those of the contaminant to ensure its dissolution and a subsequent transport. Moreover, the anolyte should be composed by a solution of sodium hydroxide (NaOH) 0.20M to prevent the generation of hydrogen ions at the anode, which can perturb the action of EDTA, since the optimum pH should be over 8.

The evolution of current is plotted in Figure 7. The current intensity increases with the EDTA concentration during the first 150 hours of processing, and remains fairly constant except for one concentration of EDTA (0.05M). When 0.10M and 0.20M of EDTA are used, the current attains stable values which are respectively 7.2mA and 7.6mA. Knowing that the total current intensity is proportional to the ions mass fluxes, the transport of lead is expected to be more efficient in this case.

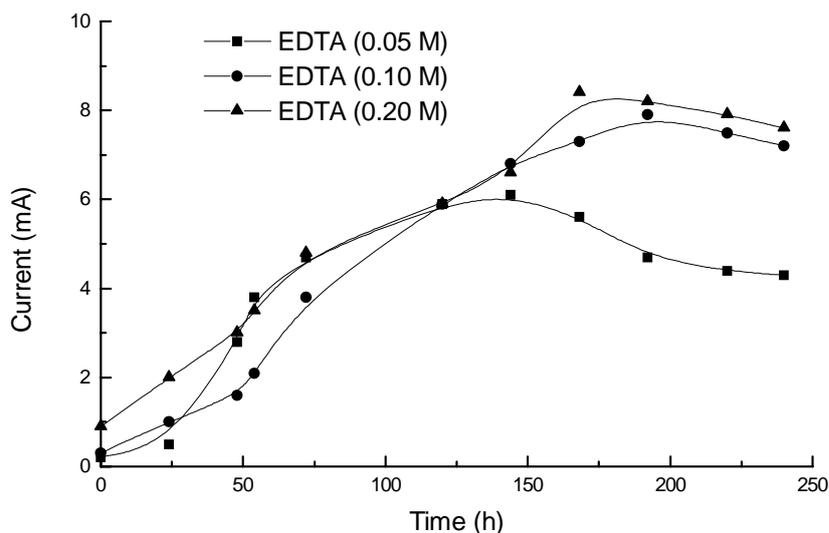


Figure 7. Current variation as a function of time for electrokinetic remediation using EDTA at various concentrations

The variation of voltage as a function of the normalized distance from the cathode is represented on the Figures 8a, 8b and 8c. When a solution of 0.05M EDTA is used as a circulating process fluid (Figure 8a), the electrical potential gradient decreases until a period of 144 hours. For experiments involving high concentrations of EDTA, the electrical potential gradient is well established after a processing period of 96 hours (Figures 8b, 8c) and remains constant until the end of the experiments with a mean value of 1.5V/cm and 1.8V/cm for runs number 6 and 7 respectively. The electric field appears to be constant during all the experiment contrarily of those where pure water is used.

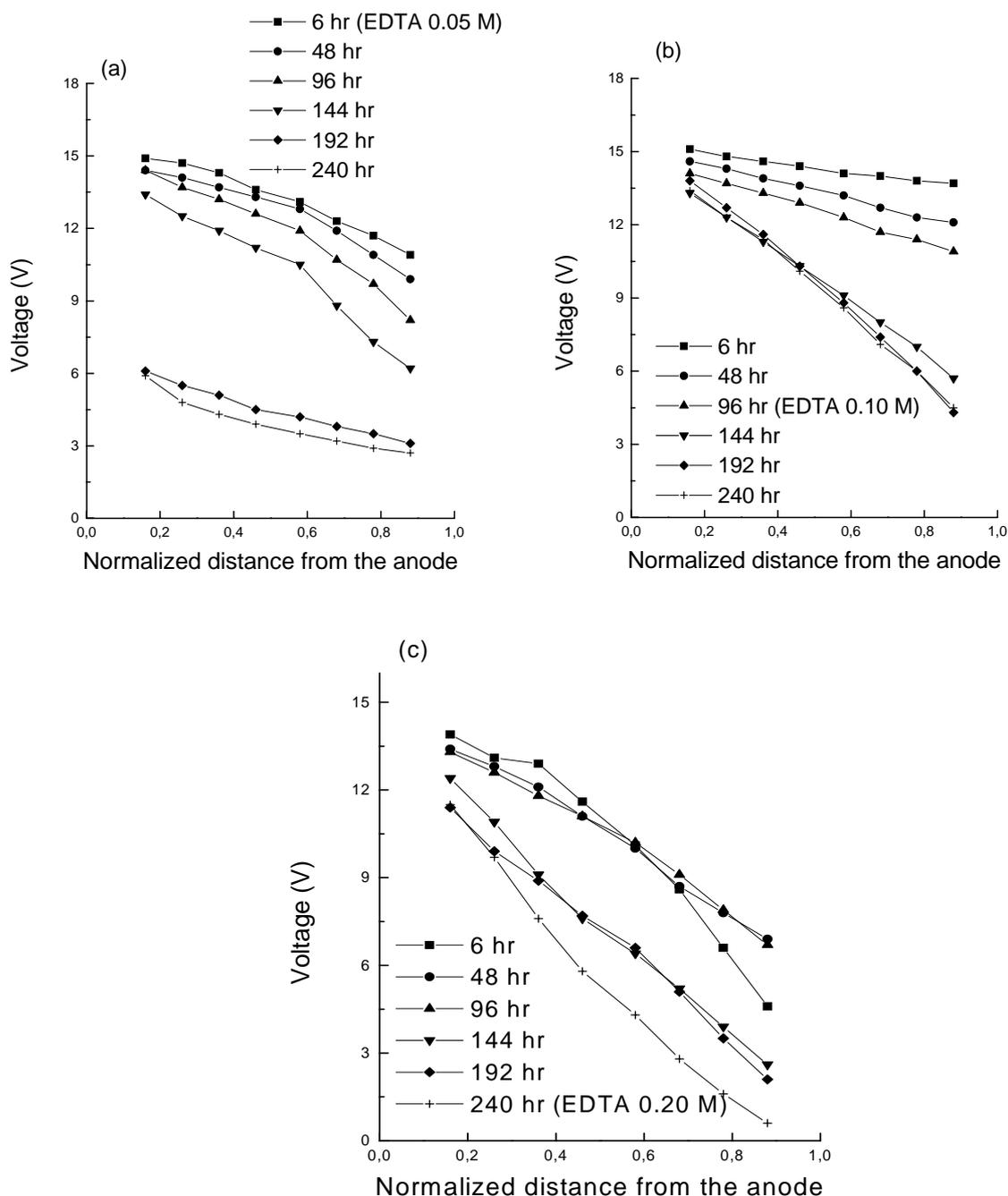


Figure 8. Evolution of the ddp from the cathode as a function of time for electrokinetic remediation using EDTA at various concentrations

The use of sodium hydroxide in the anolyte has the advantage of maintaining the soil pH in the optimum range for EDTA–lead complexation as illustrated in Figure 9. The soil pH which corresponds to the lowest EDTA concentration is high enough near the cathode to create a probable competition between EDTA ligand and hydroxyl ions for interaction toward lead.

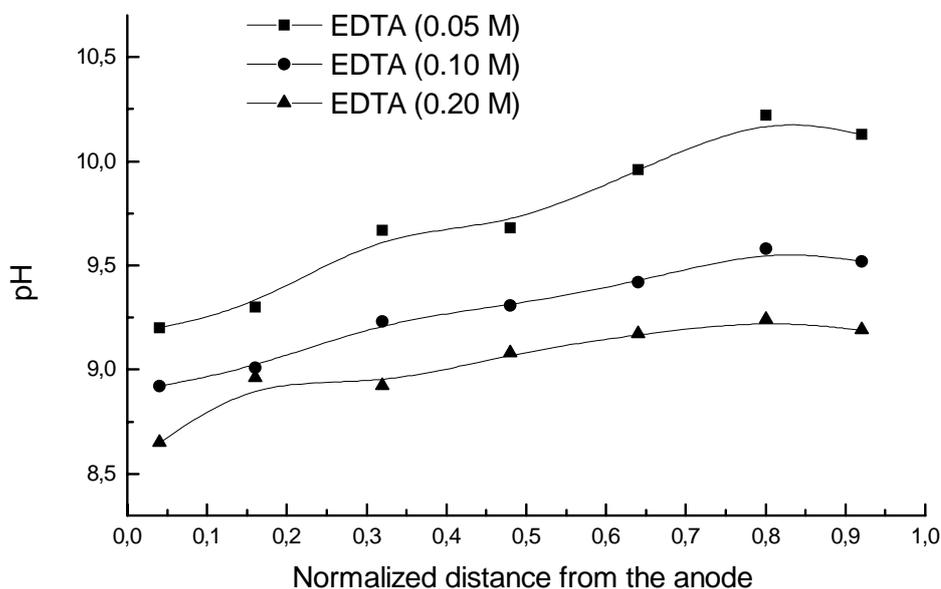


Figure 9. pH values inside the soil at the end of experiments using EDTA

Contrarily to acetic acid medium, the lead transport through the use of EDTA enhanced tests occurs from the cathode to the anode. It is owed to the formation of anionic complexes of Pb–EDTA. The accumulation of species (Table 5) is not observed as in the previous tests except for 0.05M EDTA test (in section 3).

Table 5

Lead distribution between the electrodes after 240 hours (only for run 8) of electroremediation with adding EDTA (Run 5: EDTA, 0.05M, NaOH 0.2M; run 6: EDTA, 0.10M, NaOH 0.2M, run 7: EDTA, 0.20M, NaOH 0.2M; run 8: EDTA, 0.10M, NaOH 0.2M, 1012h)

Run number	5	6	7	8
Anode (mg)	17.20	49.38	70.46	84.65
Anolyte (mg)	25.70	37.54	40.81	177.98
Filter paper (mg)	0.18	1.21	4.58	0.46
Section 1 (mg.g ⁻¹)	4.21	3.45	3.10	0.85
Section 2 (mg.g ⁻¹)	4.37	3.87	3.50	1.29
Section 3 (mg.g ⁻¹)	4.66	3.02	2.83	1.35
Section 4 (mg.g ⁻¹)	4.38	4.24	4.21	0.87
Section 5 (mg.g ⁻¹)	3.40	3.92	4.30	0.92
Section 6 (mg.g ⁻¹)	3.05	2.43	2.55	0.98
Section 7 (mg.g ⁻¹)	2.54	2.13	1.82	1.10
Filter paper (mg)	0.00	0.87	1.22	0.31
Catholyte (mg)	16.21	11.23	9.47	17.26
Cathode (mg)	0.07	0.00	0.00	0.10
Total lead (mg)	401.36	395.43	413.64	375.05
Initial lead (mg)	414.05	410.41	407.68	408.60

In all experiments, lead concentration decreases when moving away from the cathode. The removal ratios for this set are also increasing when using a high concentration of EDTA in the catholyte. For the higher EDTA concentration (0.20M), 60.0% of the initial lead is extracted from the soil adjacent to the cathode, and 56.0% from section 6. Approximately 90.0% of the contaminant is found in sections 4 and 5, but less than 62.2% in section 3. The almost extracted lead is found in the anolyte or electrodeposited at the anode as shown in Table 5. In order to improve the transport of lead, another test involving the use of 0.10M EDTA is carried out for 1000 hours of duration. All the operating conditions remain unchangeable, except that the processing fluids are renewed continuously after a period of 250h. Figure 10 shows the speciation of lead in the different sections of soil at the end of the experiment.

The total contaminant removal ratio is up to 76% in the whole specimen, meanwhile we note that the relative concentrations of lead in the involved fractions remain fairly constant. In sections 4–6 near the cathode, lead removal ratio approaches 80.0% of the total content. In the neighbour of the anode, the fraction of remaining lead decreases from 29.7 to 18.7%. As expected, a longer time processing can aid the species transport by providing a longer contact period between the target species and the chelating reagent prior to their movement as charged complexes.

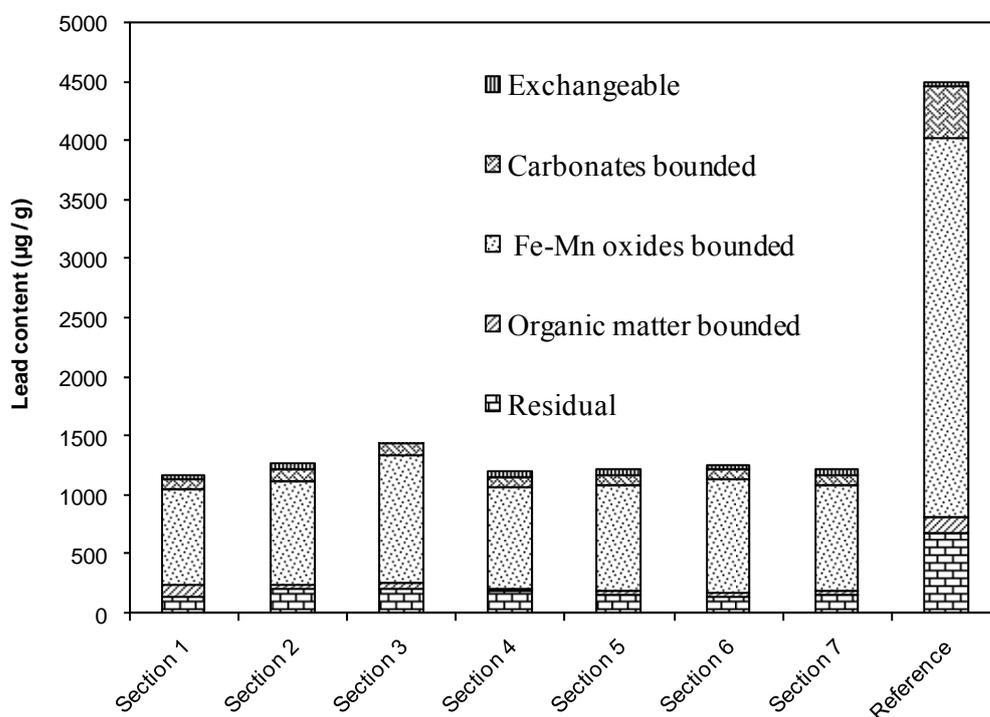


Figure 10. Lead distribution inside the section after 1012 hours of electrokinetic remediation using 0.1M EDTA

Results have shown again that the electroremediation can be perturbed by the precipitation of contaminants inside the soil after their contact with hydroxyl ions. This phenomenon which is owed to the water electrolysis provokes the formation of high resistance zones due to insoluble precipitates. The potential difference measured along the soil sample have straight forms as a function of the distance from the cathode and their slopes represent the electric field value according to the relation $E = \Delta U/d$. In pure water, weak slopes are observed at the beginning of the experiment and an increase of the voltage is occurred showing the role of hydroxides in the increase of the resistance. After 96h, on the Figure 3, two different slopes appear showing a greater electric field strength near the anode linked to the acidic medium which gives rise to a great mobility for ions while near the cathode weak slopes are observed showing that the electric field values are low. This result illustrates very well the relation between the solid phases which appears inside the soil and the increase of the resistance.

Unique slope is observed in both acetic acid and EDTA media showing that the electric field is constant along all the soil specimen during all experiment. There are not two distinct parts where hydroxides appears in one of them and a desorption with acid occurs in the other. On the other hand, the decrease of the global voltage (not the electric field) as a function of time observed in the two kind of tests can be linked to the increase of conductivity which indicates a good desorption of the contaminants. Concerning the slopes, they are not very high in the acetic acid medium. It is probably owed to the presence of acetic acid not dissociated which increases the resistance. In the EDTA medium, slopes values increases with both the EDTA concentration and time. This fact, shows that EDTA desorbs very well the contaminant and Y^{4-} ions favours the current transport. It is illustrated by a great value of the electric field which is constant during all experiments. These voltage measurements have shown the current behaviour versus the medium and as a function of time and they explain the better results obtained for the EDTA use. The conductivity of the medium is an important parameter to the success of the process. In addition to these phenomena, the main mechanisms involved in an electroremediation are electromigration and electroosmosis, however, according to the current density, water electrolysis occurs near the electrodes giving rise to an important pH variation in the soil treated and in the adjacent solutions. This phenomenon provokes a precipitation of some metals hydroxides near the cathode or inside the soil. Results are showing that we are in a case of low mobility of the proton according to the pH variation observed on the Figure 5. It can be owed to the high buffering capacity of the studied soil as it shown on the Figure 11. Thus, OH^- ions can cross a more long way through the soil specimen.

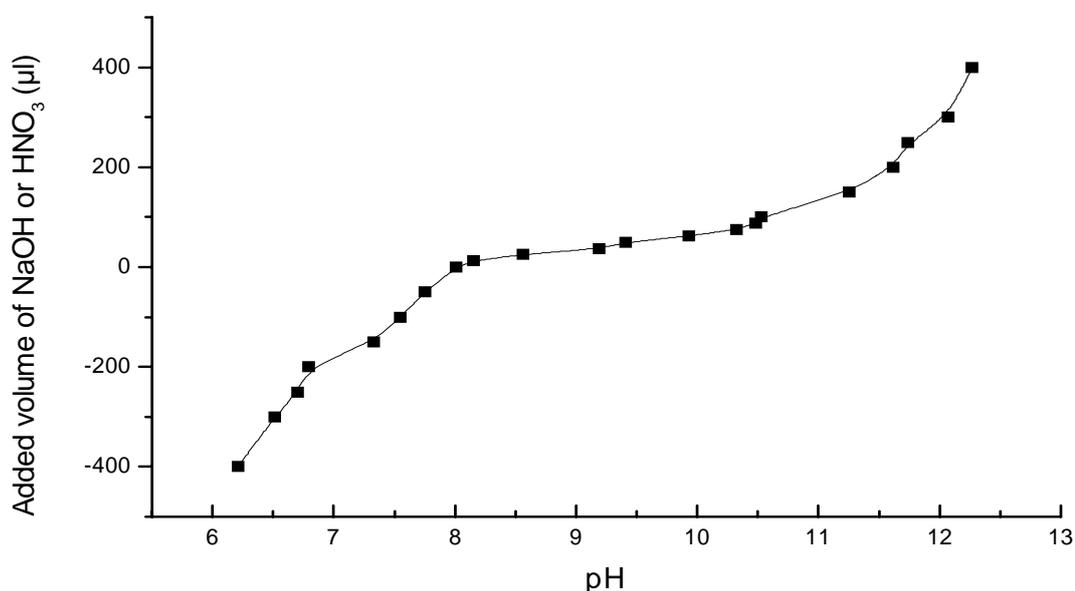


Figure 11. Acid/ base curve capacity of the soil (sign- take account the HNO_3 adding and the sign + take account the $NaOH$ adding)

The use of acetic acid has improved the soil remediation, however its action has been limited by the buffering capacity of the soil which gives rise to neutral pH at the end of the experiment. This buffering capacity is also owed to the high content of calcite in this soil (Table 1). Thus, a natural alkalinity appears and neutralises the effect of acetic acid. The transport of lead which occurs from the anode to the cathode shows that acetate ions do not play a role in the dissolution of the contaminant. The lead desorption is carried by the action of the acid produced by the anode added to those which comes from the acetic acid dissociation.

The use of EDTA appears as the better solution of the handicap caused by the hydroxide precipitation. However, lead is not totally removed. A limitation of the desorption is observed by the fact that the pH cannot be well controlled. Both water electrolysis and buffering capacity of the soil are two parameters which play a great role in the pH soil variation, then, they influence the formation of the complex PbY^{2-} . A part of hydroxide can be formed if the soil pH is acid or too alkaline. This result shows the higher mobility of lead in these operating conditions.

4. CONCLUSIONS

An electroremediation of a soil contaminated by lead has been studied through three reagents. The use of pure water has shown the limiting conditions caused by the hydroxides precipitation. The neutralisation of the cathode electrolysis reaction by means of acetic acid even at pH less than 2.5 is not sufficient to extract lead species regarding to the buffering capacity of the soil and the low dissociation of the acetic acid while the use of EDTA in the catholyte enhances the transport of lead in the specimen. The buffering capacity and the resistance of the soil appears as two very important parameters adding to the pH for the optimisation of this process.

The optimisation of all parameters for this soil shows that a run with 0.1M EDTA in the catholyte and 0.2 M of sodium hydroxide in the anolyte and a constant voltage corresponding to an electric field strength of 1 V/cm during 1012 hours allow to remove up to 76.0% of the total lead content. The work carried out described in this paper has shown again the soil versatility towards electrokinetic treatment (Akretche, 2002).

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