

Removal of Lead from a Calcareous Soil by Chloride Complexation

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Remediation of a lead-contaminated calcareous soil using NaCl solutions was examined. The removal of Pb from a coarser fraction of the soil was found to be 83% after three successive extractions at a NaCl concentration of 8 M, whereas an average of 9% of the calcium was removed. Multibatch extractions of Pb from finer soil containing a higher level of Pb were also

performed. The removal of Pb from this soil after six successive extractions with 8 M NaCl was found to be 93%. The removal of Pb increased with time in a batch test and approached 80% after 90 h. It was found that the data were adequately described by a first-order rate, and hence it is believed that a single reaction mechanism controlled the release of Pb (i.e., from carbonate bound or exchangeable Pb fractions in the soil). Increasing removal of Pb was found as the volume of water added was increased as the mass of NaCl in solution remained constant. The removal of Pb from the leachate was found to be 90%, 99.7%, and 35% with lime (25.20 g/L), sodium carbonate (4.48 g/L), and calcium carbonate (82.0 g/L) addition, respectively. In the case of sodium carbonate, the removal of Pb was further improved when the pH was adjusted to 8.2. The recycling of free chloride that was generated from leachate resulted in 91% removal of Pb from the soil (particle size ≤ 4.75 mm) after six recycles.

KEY WORDS: Soil washing, extraction, kinetics, precipitation, lead removal, calcareous.

INTRODUCTION

Metallic lead and lead compounds generally are the principal contaminants of concern in soils that are contaminated by battery wastes. Other heavy metals such as cadmium, copper, arsenic, antimony, and selenium are often present in such soils, but usually at much lower concentrations than lead and often below hazardous concentration levels.

Lead is generally not very mobile in soil and tends to be retained in the upper few centimetres of the soil (Jensen *et al.*, 2000). The capacity of soil to adsorb lead increases with increasing pH, cation exchange capacity, organic carbon content, redox potential, and phosphate levels. Lead exhibits a high degree of adsorption on clay-rich soils. Lead compounds can also be adsorbed onto hydrous oxides of iron and manganese and thus be immobilized. Some lead compounds are slightly soluble in water, while others are insoluble in water. The solubility of lead increases at both low and high pH.

Despite the general lack of mobility, lead can migrate vertically in certain soil types and at appropriate pH levels and may have an impact on groundwater resources. In coarse sandy subsoils, elevated levels of Pb, Zn, and Cd were found in groundwater 3 m below the ground surface at a car battery site (Jensen *et al.*, 2000). In the unsaturated soil, the pH had decreased to about 3.5, thereby facilitating the migration of the metals. The acid from the car batteries presumably caused this low pH value. The risk of metal migration to the groundwater is limited as long as pH stays > 6.5 in the top soil. The abandoned car battery disposal site operated directly on the ground surface, thereby leading to very high concentrations of metals in the soil and the migration of metals that may have affected the groundwater.

Once heavy metals mobilize, they may enter the food chain either through water supplies and aquatic life or through agricultural products and grazing animals. The effects of toxic heavy metals in soil on human health are difficult to predict, and it is difficult to set up threshold concentrations above which toxicity can occur. However, washed soils are considered to be sufficiently clean if the lead concentration has been reduced to meet the specific regulation limits. In Quebec, the Ministry of the Environment and Forests (MEFQ) allows soil to be disposed of on land when it meets an A level requirement of less than 50 mg/kg (background level), whereas B (150 mg/kg) and C (600 mg/kg) levels require further investigation and cleaning up, respectively (MEFQ, 1994). Stringent environmental regulations have encouraged the development of new treatment technologies for soil decontamination. The development of new techniques has focused mainly on soils contaminated with organic pollutants, while few innovative technologies have been developed and applied on a commercial scale for the remediation of metal-laden soils. The remedial options are either to extract metals from the soils or to fix metals in an insoluble form (immobilization). The extraction of metals by chelating agents or acids is a permanent solution to metal pollution problems,

whereas immobilization (fixation) techniques often require long-term monitoring of the site.

Four main categories of extracting reagents have been used in the past to decontaminate soils that are polluted by heavy metals:

1. Strong acids such as sulfuric, hydrochloric, and nitric acids. (Benschoten *et al.*, 1994; Reed *et al.*, 1995; Reed *et al.*, 1996).
2. Chelating agents such as ethylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA), nitrilotriacetic acid (NTA), etc. (Wasay *et al.*, 1998a; Prasso *et al.*, 1997; Pichtel and Pichtel, 1997; Steele and Pichtel, 1998; Elliot and Brown, 1989; Papassiopi *et al.*, 1999; Heil *et al.*, 1999; Theodoratos *et al.*, 2000; Wasay *et al.*, 2001).
3. Weak organic acids such as acetic and citric acids, etc. (Wasay *et al.*, 1998a and 1998b; Leidmann *et al.*, 1994).
4. A weak inorganic chelating agent such as chloride ion has also been used to extract Pb from a contaminated soil (Reed *et al.*, 1996).

Both HCl and HNO₃ have been found to be effective in removing lead from soil (Reed *et al.*, 1995). However, hydrochloric acid was found to be more effective in removing Pb from a contaminated soil when compared with HNO₃ and H₂SO₄ (Benschoten *et al.*, 1994). The main advantage of the strong acids for soil cleaning is that they cost-effectively remove heavy metals such as lead from the soil. The disadvantage of using strong acids is that the physical, chemical, and biological properties of the soil are destroyed.

EDTA has been used extensively as a chelating agent for soil decontamination. EDTA has been used to treat calcareous and alkaline soils contaminated by Pb from mining and battery industry sites (Papassiopi *et al.*, 1999; Heil *et al.*, 1999; Theodoratos *et al.*, 2000). However, EDTA reduces the hydraulic conductivity of the contaminated soil due to dissolution of CaCO₃ and the development of CO₂ gas in the soil pores. In addition, EDTA can remove other nutrients from the soil, including organic matter.

The use of weak organic acids as chelating agents to remove lead from the soil is considered more environmentally friendly. Several weak organic acids such as citric, oxalic, tartaric, acetic, succinic, phthalic acids, etc. have been used to remediate soil contaminated by heavy metals (Wasay *et al.*, 1998a, 1998b; Leidmann *et al.*, 1994). From these studies, it was found that the citric and tartaric acids were very effective in removing Pb from different soil types. A problem with using these weak acids is that they are difficult to regenerate.

A weak inorganic chelating agent such as chloride ions was used previously for the extraction of Pb from a lead ore (Dutrizac, 1992). The lead sulfide ore (PbS) was oxidized to lead sulfate (PbSO₄) during extraction with a concentrated chloride solution (4 to 6 M). Lead removal from soil contaminated by lead battery waste disposal has been examined

using 4 to 6 *M* chloride solutions for acidic soil. Chloride solutions have been found to be as effective as EDTA and HCl solutions for the removal of Pb from highly contaminated soils (Nedwed and Clifford, 2000). The extraction of soil with NaCl at low pH (~4) may disturb the properties of the soil, and hence may cause a disposal problem.

The problems of disturbance of soil properties, regeneration of extractant, and disposal costs show that there is a need to develop an economical and environmentally friendly remediation process for soil contaminated by heavy metals such as lead. In this study, experiments were carried out for the extraction of lead from a contaminated soil using a chelating agent such as NaCl. The contaminated site selected was an abandoned lead battery-processing factory in Quebec, Canada, that operated between 1913 to 1980. The objectives of this study were

1. To characterize soil samples for metals such as Pb, Cu, Cd, Zn, and Ca;
2. To establish relationships between NaCl concentration and Pb and Ca leaching;
3. To establish the kinetics of Pb leaching with NaCl from a contaminated soil;
4. To evaluate Pb removal from the leachate using different precipitants; and
5. To evaluate the recycling of the leachate for soil remediation.

MATERIAL AND METHODS

Characterization of Soil

The soil under study was obtained from an abandoned lead battery industry site at St-Jean-Sur-Richelieu in Quebec, Canada. The factory operated from 1913 to 1980 (Skinner and Salin, 1995). A soil sample was collected at 25 to 30 cm depth for heavy metals characterization. The soil was dried and sieved to particle sizes ≤ 4.75 mm. The pH, Pb, and other metal contents were then measured. The concentration of metals was determined by digesting the sieved soil with concentrated nitric acid at a temperature at 80 to 95°C for 12 h. The concentration of metals in the extract was determined by an inductively coupled plasma-atomic emission spectrophotometer (ICP-AES). Similarly, a finer soil of particle size ≤ 2 mm was also analyzed for heavy metals to compare with the coarser soil in terms of remediation. The coarser soil sample was studied mainly due to its availability in the laboratory.

Extraction Tests

To test the effect of NaCl concentrations on Pb leaching, a series of seven flasks containing 50 ml of NaCl solution were prepared. The mass of NaCl in the flasks

varied from 0.73 to 23.40 g and hence the concentrations varied from 0.25 *M* to 8.0 *M*. About 10 g of soil was added to each flask, and they were subsequently shaken for 90 h at 170 rpm at room temperature (20°C). Each flask was then filtered (0.25 µm glass fiber filter) and the pH of the filtrate was measured. Each filtrate was analyzed for Pb, Cd, Zn, Cu, and Ca by ICP-AES with some of the soil samples analysed in duplicate. The residual soil samples were twice extracted with the same concentration of NaCl. A finer soil sample (size ≤ 2 mm) was similarly extracted six times with fresh 8 *M* NaCl solution.

In addition, soil samples were extracted with a fixed amount of NaCl and increasing volumes of deionized water. A series of four flasks were prepared containing 10, 20, 30, and 50 ml of deionized water. About 10 g of soil sample was added to each of the flasks and then 23.4 g of NaCl was added to each flask. The resulting mixtures were shaken for 90 h at 170 rpm at room temperature. The mixtures were filtered, and the filtrates were analyzed for Pb by ICP-AES. A single extraction was carried out in this case.

A study was carried out to assess the kinetics of leaching of Pb from the soil. In this study 10 g of soil was added to each of a series of six flasks containing 50 ml of 8 *M* NaCl solution. The flasks were shaken at 170 rpm at room temperature. At selected intervals in time over a period of 2 to 90 h flasks were sacrificed and three successive extractions were carried out on the soil in each sample. For each sample, the soil slurry was filtered, and the filtrate was collected for Pb analysis by ICP-AES and pH measurement. Some of the soil samples were analyzed in duplicate.

Leachate Treatment

The leachates from the various extraction experiments that employ 8 *M* NaCl solution were collected and treated by different precipitants. Lime (calcium hydroxide) addition was evaluated in three flasks that contained 25 ml of leachate. The dosage of lime varied from 0.08 to 0.341 *M*. Pb precipitation with Na₂CO₃ was evaluated in a series of 10 flasks containing 25 ml of leachate that were dosed over a range of concentrations from 0.04 to 3.8 *M*. An additional experiment was also conducted with a series of three flasks that contained 0.2 *M* Na₂CO₃ that were pH adjusted with a dilute HCl solution. The use of CaCO₃ as a precipitant was evaluated in a series of six flasks that were dosed to achieve concentrations ranging from 0.044 to 0.82 *M*.

After dosing, all the leachate-precipitant mixtures were shaken for 2 h at 170 rpm at room temperature. The suspended liquid in each flask was filtered, the filtrates were analyzed for Pb by ICP-AES, and the pH levels were measured.

Recycling Process

Approximately 10 g of soil was treated with 8 *M* (23.4 g NaCl in 50 ml deionized water) by shaking the mixture for 90 h. The soil was filtered, and the filtrate of the

leachate was treated using 0.04 *M* (4.48 g/L) sodium carbonate to remove Pb. The suspended precipitate was filtered, and the filtrate was added to the residual soil (which was collected on filter paper from a previous extraction and transferred to the flask) for further removal of Pb. This cycle was repeated six times and after each cycle a few milliliters of filtrate was taken for analysis, and the rest was recycled for the further extraction of Pb from the soil. This recycling was compared with extracting the soil six times with pure NaCl solution (8 *M*).

RESULTS AND DISCUSSION

Soil Characterization

The results of the soil characterization for particles smaller than 4.75 mm and 2.0 mm are presented in Table 1. Lead was the dominant heavy metal found in the soil. The samples taken at depths from 25 to 30 cm contained approximately 3200 mg Pb/kg for soil particle size ≤ 4.75 mm, while the smaller fraction (< 2.0 mm) contained approximately 13,200 mg/kg. Lead concentrations were far above the permissible limit of Pb for Quebec's soil criteria (MEFQ, 1994). The concentrations of Cu, Cd, and Zn in the soil were substantially below the permissible limits. These heavy metals were not included in further study.

Extraction Tests

The effect of NaCl concentration on Pb and Ca leaching from the soil was studied with the soil sample sequentially extracted three times for each concentration of NaCl. The pH of the final solution was measured to be 7.7, and hence pH was not a significant factor impacting on extraction. The removal of Pb in each extraction as well as the total lead removal over the three sequential extractions at each NaCl concentration was plotted as a function of NaCl concentration in Figure 1. From Figure 1 it can be seen that the removal of lead from the soil was relatively small for NaCl concentrations less than 2 *M*. Above 2 *M* the removal of Pb increased

TABLE 1
Metal Concentrations in Soil (mg/kg)

Soil	Pb		Ca		Cu		Cd		Zn	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
≤ 4.75 mm	3205	6	8565	18	0.7	0.01	0.07	0.001	34	0.5
≤ 2.0 mm	13240	348	155220	935	35.3	1.4	N.D.	N.D.	166	9

Notes: N.D. = Below Detection Limit
SD = Standard Deviation

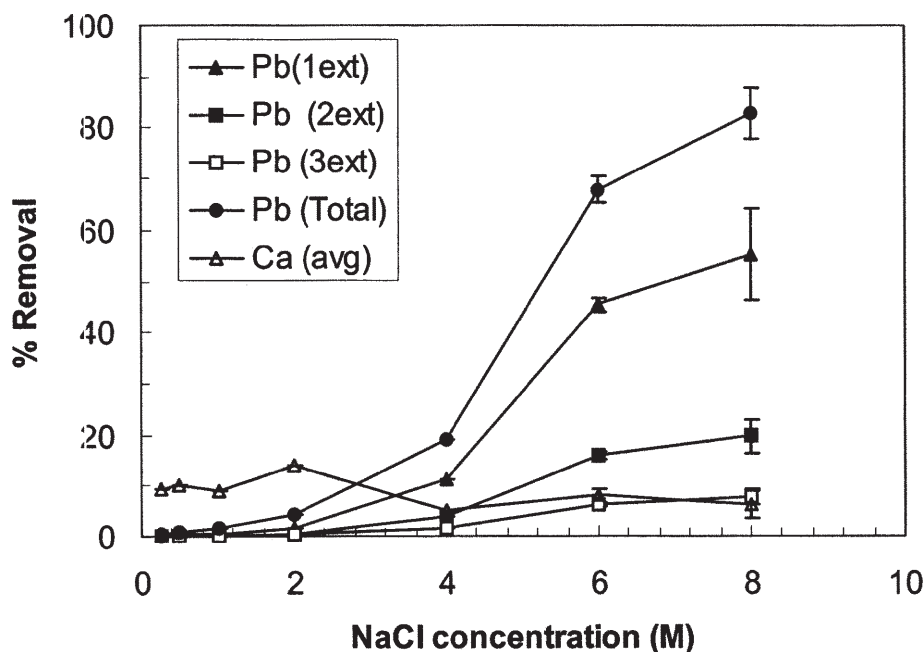


FIGURE 1

Removal of Pb and Ca as a function of NaCl concentration. Three successive extractions: First extraction Pb (1ext), second extraction Pb (2ext) and third extraction Pb (3ext).

substantially over the range of NaCl concentrations from 2 to 6 M and appeared to start to plateau at concentrations near 8 M. The cumulative percentage removal of Pb was found to be 83% at an NaCl concentration of 8 M. The residual Pb after three extractions was 544 mg/kg, which is above the B-level according to the MEFQ standards (MEFQ, 1994).

From Figure 1 it can be seen that the extraction efficiency decreased substantially from the first to the second and third extractions. In a previous study, it was concluded that most of the Pb in the soil was either associated with metals oxides or bound as PbCO_3 (Wasay *et al.*, 2001). The results of this study would suggest that Pb in this fraction was easily removed by dissolution with chloride ions. The reduced efficiencies in the latter extractions were likely due to the stronger bonds between Pb and the other soil components such as the organic fractions. In the previous study (Wasay *et al.*, 2001) it was found that only a very small fraction (2%) of the Pb was deemed to be in the residual fraction from a series of sequential extractions. This fraction, which may include metallic Pb, likely constituted a portion on the nonextractable Pb.

Multiple extractions of Pb were also carried out with the finer soil containing a high concentration of Pb (Pb 13, 200 mg/kg, soil size ≤ 2 mm). The cumulative

percentage removal of Pb with an 8 M NaCl solution was plotted as a function of the number of extractions (Figure 2). From Figure 2 it can be seen that the removal of Pb increased as the number of extractions increased; however, the removals appear to have been approaching a fixed value. The percentage removal of Pb, was found to be more than 93% after six successive batch extractions of the soil. The residual soil contained 924 mg/kg of Pb and the results suggest that little additional lead would be removed by subsequent extractions. Hence, a fraction of the Pb was bound in a manner that was not available to be released by NaCl chelation. The results presented in Figure 2 confirm those observed in the tests that evaluated the soil that included the coarser soil components.

It was examined whether the Ca content of the soil was detrimentally impacted in the extraction process. In Figure 1 the total Ca extracted at each NaCl concentration is presented, while in Figure 2 the cumulative extracted Ca is presented. From Figure 1 it is apparent that lead was leached out to a greater extent than Ca for NaCl concentrations greater than 2 M. Hence, all remaining extractions were performed at NaCl concentrations that were substantially higher than 2 M. From Figure 2 it can be seen that more than 80% of Pb was removed in the extractions, while the removal of Ca was 9%. It can be concluded that at concentrations greater

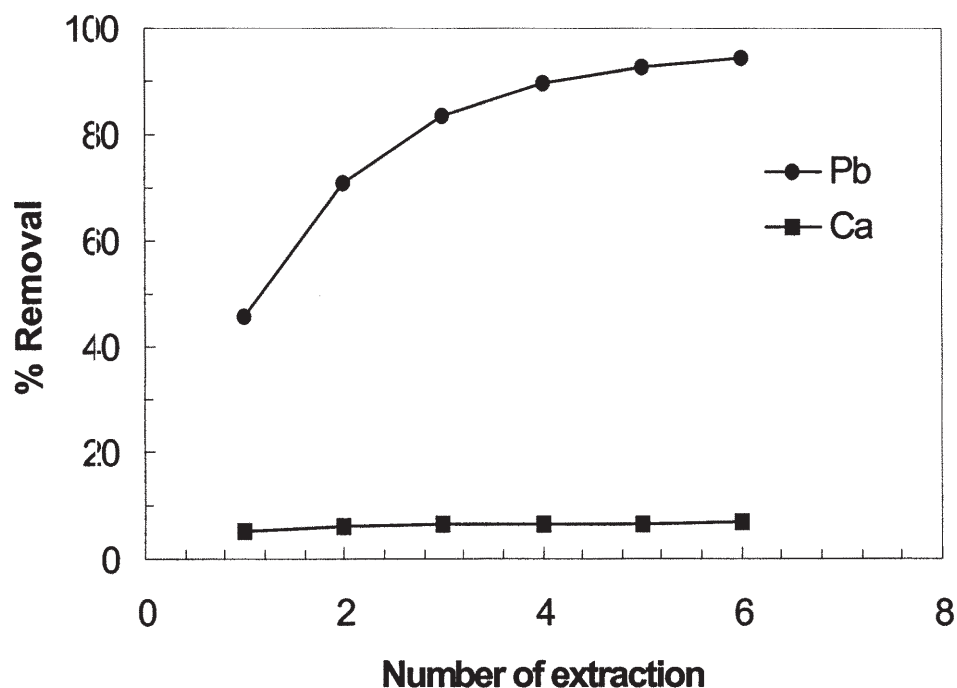


FIGURE 2

Cumulative percentage removal of Pb and Ca from fine fraction of soil (particle size < 2 mm) vs. number of extractions with 8 M NaCl solution.

than 2 M, NaCl was effective for selectively removing Pb with a negligible amount of Ca leaching. It is interesting to contrast the removal of Ca that was observed in the present study with NaCl, to that which was observed with EDTA in a different study (Heil *et al.*, 1999). In the study by Heil *et al.*, 90% of the Ca was removed by the EDTA, thereby consuming significant quantities of EDTA as well as depleting the Ca content of the soils. The results of this study clearly illustrate the benefits of using NaCl solutions for removing Pb from calcareous soils.

The superior removal efficiencies of Pb relative to Ca likely resulted from the higher solubility constant of the PbCl_4 complex when compared with that of CaCl_2 (Sillen, 1964). Equation 1a, b, c describes the reactions that would have taken place between Pb present in soil and chloride ions.



The chloride ions in solution can exchange carbonate (CO_3), sulfate (SO_4) ions, or adsorbed Pb ions on metal-oxides/organic matter to leach Pb as soluble PbCl_4^{2-} complexes. Lead chloride is more soluble than PbSO_4 , PbCO_3 , Pb(OH)_2 , and PbS . The solubility of these Pb compounds increases in the presence of a high concentration of NaCl due to the formation of soluble Pb-chloride complexes such as PbCl_2 , PbCl_3^- , and PbCl_4^{2-} .

The solubility of lead in a NaCl solution is believed to be due to more than just the free chloride ion concentration (Evans, 1989). The evidence suggests that the sodium ion also interacts in the lead-chloride complex contributing to lead solubility due to the formation of an ion pair complex such as PbNaCl_4^- . In addition, the higher Pb extraction ability of NaCl was found to be due to the high ionic strength of the solution. In the presence of this high ionic strength, Pb could be exchanged with the sodium ion by a cation exchange mechanism. In low ionic strength NaCl solutions, cation exchange sites prefer divalent species such as Pb^{2+} and Ca^{2+} . At high ionic strength, electroselectivity reversal can occur resulting in the cation exchange sites preferring monovalent cations such as Na^+ over divalent ions. Due to this electroselectivity reversal, the sodium would displace Pb from the soil.

The effect of the volume of the extracting solution containing a fixed mass of NaCl (23.4 g NaCl and volumes from 10 to 50 mL) on the removal of Pb was investigated at room temperature. The mass removal of Pb was plotted as function of the volume of the extracting solution (Figure 3a) and the resulting NaCl concentration (Figure 3b). It was found that the removal of Pb from the soil increased as the volume of the extraction medium increased and the concentration of NaCl decreased. It is interesting to note that in this experiment the removal of Pb decreased as the NaCl concentration increased. This trend is the opposite of that

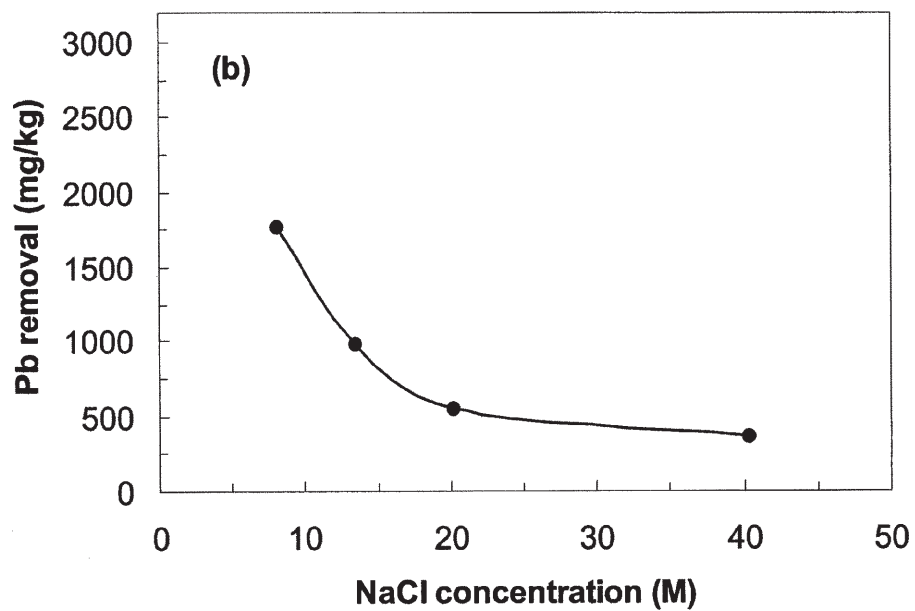
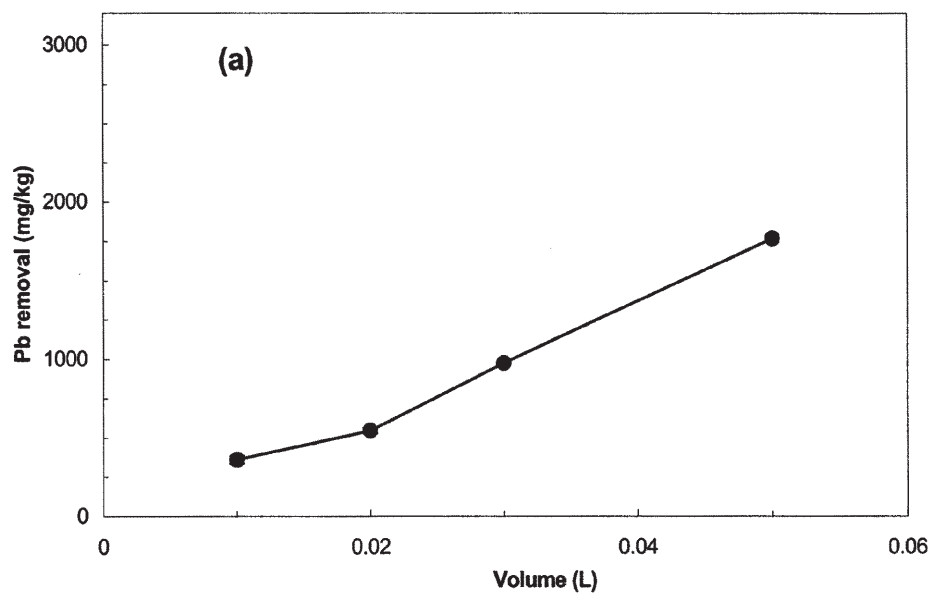


FIGURE 3

Lead removal with constant mass of NaCl (23.4 g) and varying solution volume: (a) Removal vs. volume (b) Removal vs. NaCl concentration.

which was observed in the previous studies where only the NaCl concentration was varied. It is believed that over the range of liquid-solid ratios examined in this experiment that the release of lead from the soil resulted in substantially elevated lead concentration in the solution during batch extraction. This high concentration of Pb likely limited the removal of Pb from the soil by shifting the equilibrium toward the left side of Equation 1. The results of this study would suggest that there is an optimal combination of NaCl concentration as well as liquid-solid ratio for operating a batch extraction process. Further study would be required to elucidate this condition. It is also interesting to note that this would impact on the design of any continuous treatment process that is not based on a batch treatment.

A knowledge of the kinetics of Pb removal is required for designing treatment processes that employ NaCl for removal of Pb from the soil. A study was performed to evaluate the kinetics of Pb extraction using 8 M NaCl as a chelating agent. Only Pb was focused on because the concentrations of Cd, Cu, and Zn in the soil were small and below the permissible limit of the soil. The total Pb removal after three successive extractions with 8 M NaCl was plotted as a function of contact time (Figure 4a). From Figure 4a, it can be seen that the removal of Pb increased with the extraction time and approached about 80% after 90 h. The removals that were observed at 90 h were consistent with those that were determined in the previous batch extractions.

The experimental data were evaluated against a first-order kinetic model. Figure 4b shows the plot of $\ln(C/C_0)$ as a function of time using a first order rate equation ($\ln(C/C_0) = -kt$, where C is the concentration of Pb remaining in the soil at a given time, C_0 is the initial concentration of Pb in soil at time zero, t is the time in hours, k is the rate constant). Figure 4b shows that the data fit a straight line well, indicating that the first order model was appropriate. The rate constant was found to be 0.0127 h^{-1} . In a previous study (Wasay *et al.*, 2001) it was revealed that 90.5% of the lead was retained in the oxide- and carbonate-bound fractions. These results suggest that the lead species that were present in these two dominant fractions were released at similar rates.

Leachate Treatment

The leachate generated during the soil washing process was treated with different concentrations of lime, sodium carbonate (Na_2CO_3), and calcium carbonate (CaCO_3). The solution pH and the percentage removal of Pb from the leachate were plotted as a function of lime concentration in Figure 5. It was found that over the range of lime dosages examined, the pH increased only slightly as the dosage of lime increased. The removal efficiency increased from 68 to 90% over the range of dosages examined. At the highest dosage of 0.34 M, a Pb removal efficiency of 90% was achieved and the pH of the solution was 11.8.

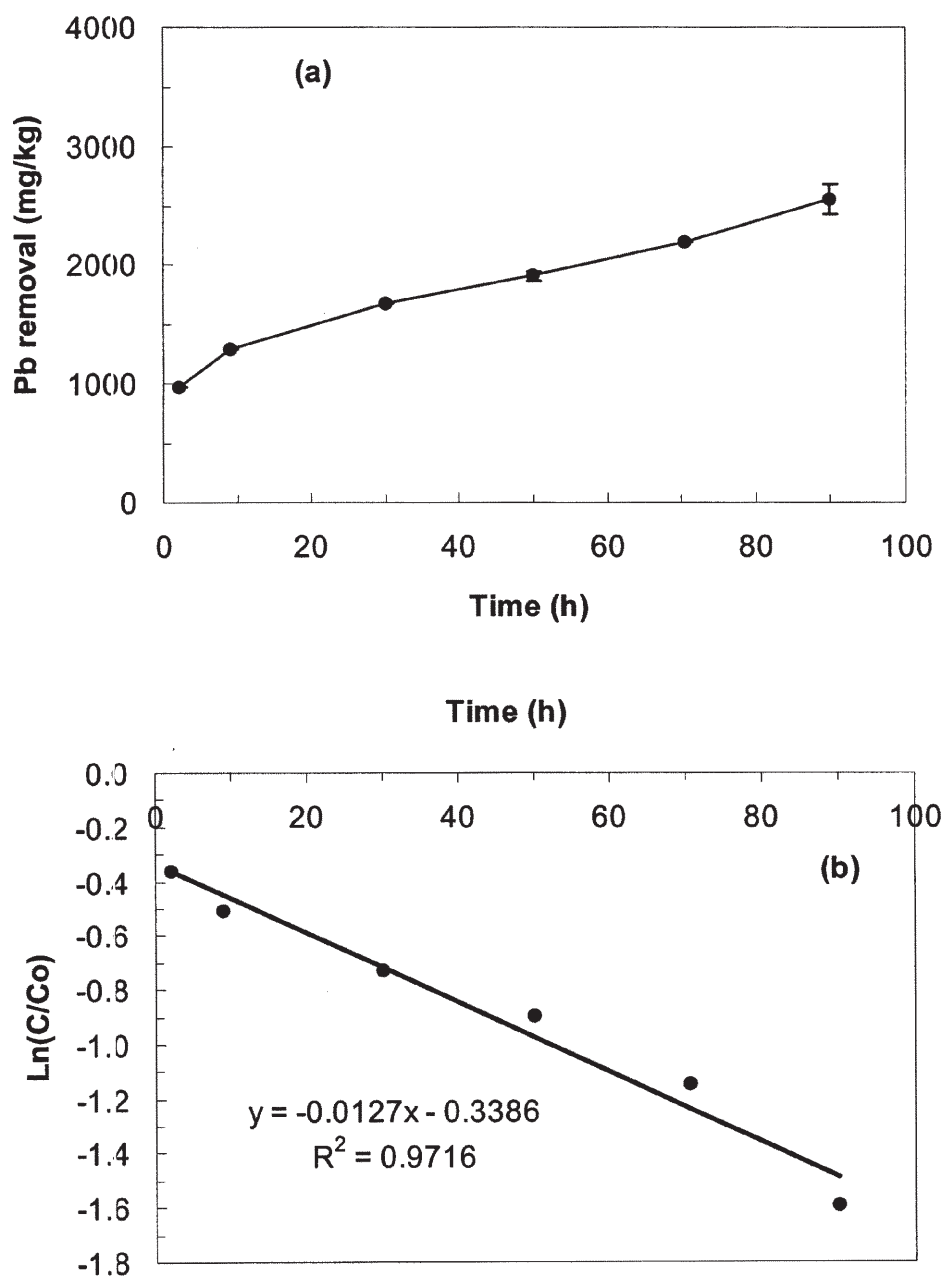


FIGURE 4

(A) Pb removal versus time. (B) First-order model of leaching kinetics.

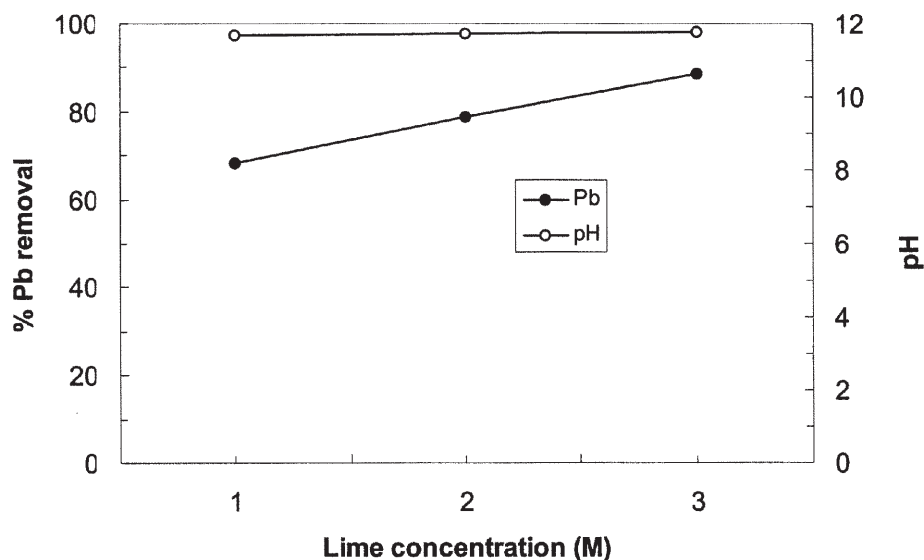


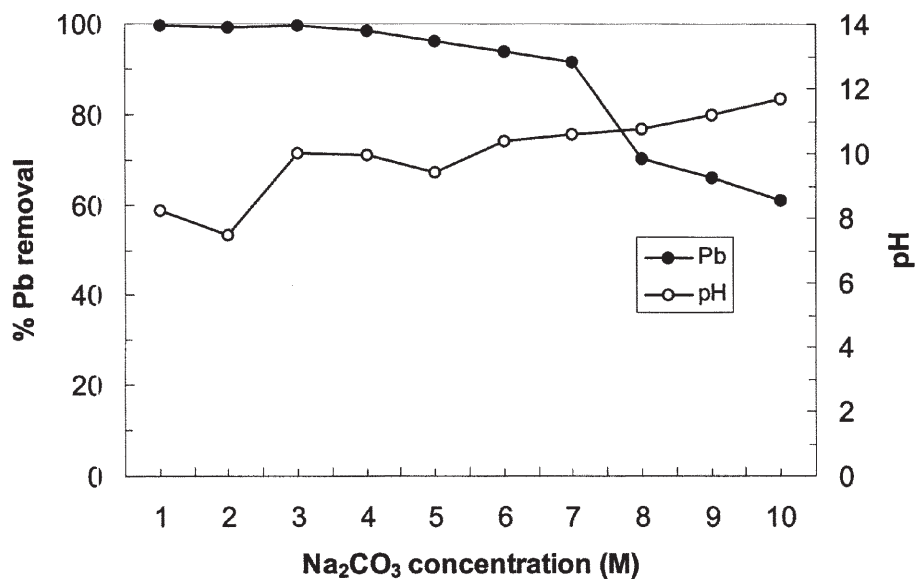
FIGURE 5

Removal of Pb from the leachate with lime.

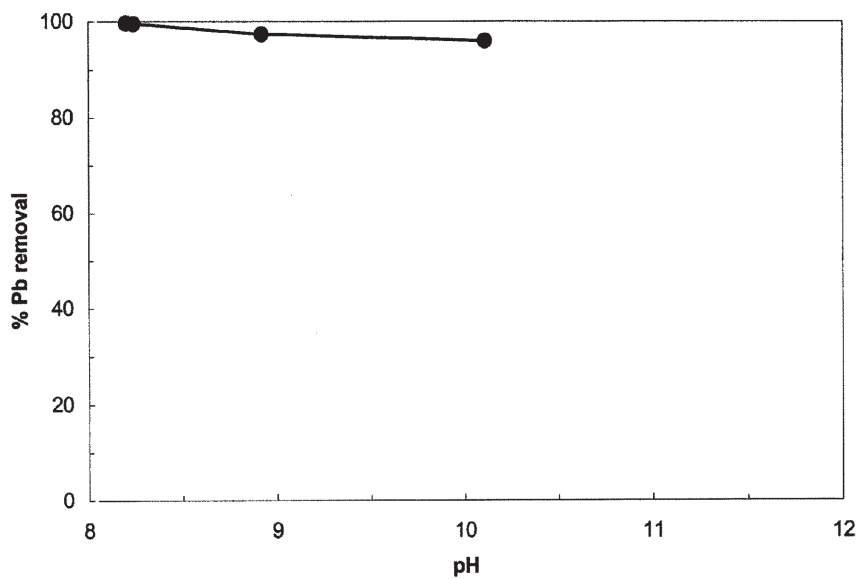
For the leachate that was treated with Na_2CO_3 , the pH and lead removal efficiencies were plotted as a function of the dosage (Figure 6a). It was found that the pH increased significantly as the concentration of sodium carbonate was increased, and that more than 99.7% of Pb was removed at the minimum Na_2CO_3 concentration of 0.04 M. This corresponded to a pH of 7.5. When the concentration was increased to 3.8 M, the Pb removal efficiency decreased to 61%. This may have been due to the high pH (pH 11) at the highest concentration of sodium carbonate. At high pH levels, Pb can form soluble complexes with carbonate and OH^- that remain in soluble form.

The treatment of the leachate was also carried out at different pH levels with a constant sodium carbonate concentration of 0.2 M. The percentage removal of Pb was plotted as a function of pH in Figure 6b. From Figure 6b it can be observed that the removal of Pb increased from 96% to more than 99% when the pH was reduced from 10.11 to 8.2. This indicates the importance of pH as a controlling factor for Pb removal from the leachate.

The removal of Pb from the leachate was also investigated with different concentrations of calcium carbonate. The pH and Pb removal efficiency were plotted as a function of calcium carbonate dosages in Figure 7. From Figure 7 it can be seen that the pH was not significantly affected as the dosage increased. In addition, it can be seen that the removal of Pb was found to be constant at about 35% when the concentration of calcium carbonate was varied between 4.4 and 8.2 g/L. The low removal efficiency may have been due to the low solubility of



(a)



(b)

FIGURE 6

(A) Removal of Pb from the leachate with sodium carbonate. (B) bPb removal vs pH with 0.04 M sodium bicarbonate

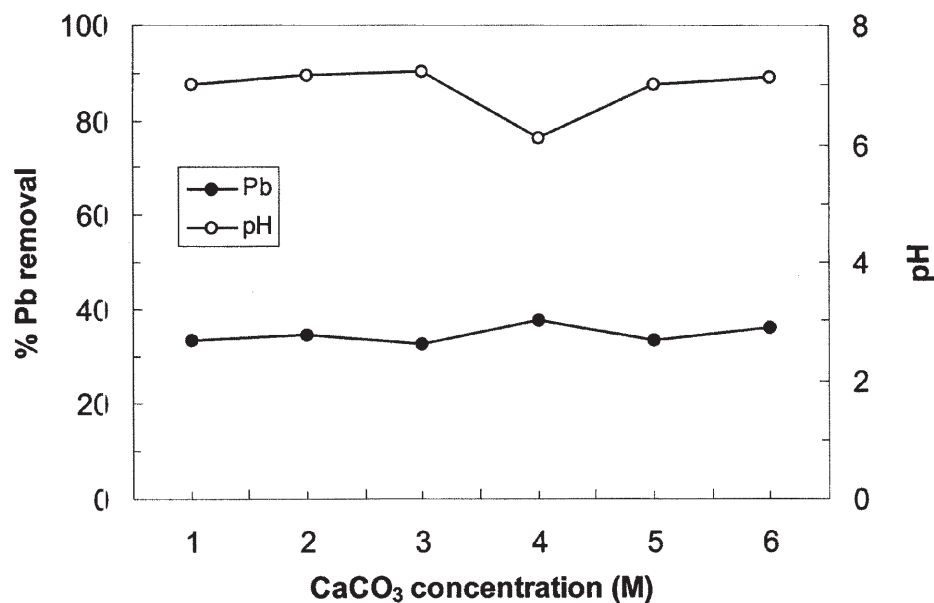


FIGURE 7

Removal of Pb from leachate with calcium carbonate.

calcium carbonate in the leachate solution. During the experiments it was noticed that some of the CaCO₃ remained suspended in the leachate.

Recycling of Recovered Chloride Solution for Pb Removal

Recycling of the treated leachate for further soil treatment was evaluated using sodium carbonate as the precipitating agent. In these experiments the soil was successively treated with an 8 M solution of NaCl and the leachate was then treated with 0.04 M Na₂CO₃ to precipitate the Pb and recover the chloride for recycling. A total of seven extractions that included six extractions with recycled leachate were performed. For comparison six extractions of a separate soil sample were carried out with fresh NaCl solution. The cumulative percentage Pb removal from the soil as a function of treatment cycle is presented in Figure 8. Included in Figure 8 for comparison is the removal that was obtained when fresh NaCl solution was employed for each of the extractions. From Figure 8 it can be seen that similar removal efficiencies were obtained for the case with leachate recycling and for the fresh solution. The removals obtained in the first few extractions were slightly higher with fresh solution when compared with those obtained with recycled leachate. However, the removals in the latter extractions were similar for both

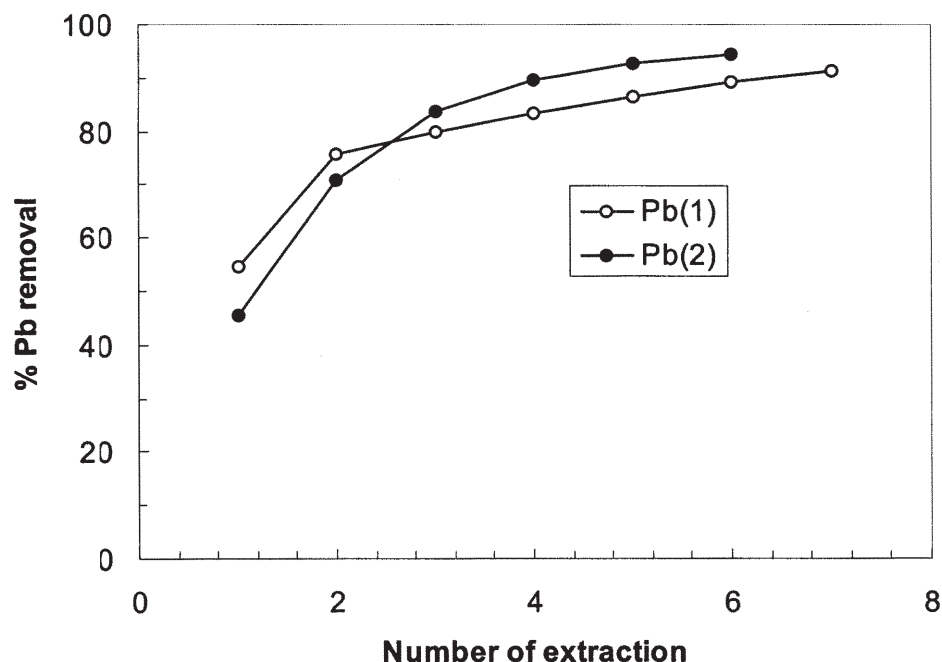


FIGURE 8

Pb removal versus extraction number: Pb (1) recycled solution, Pb (2) fresh solution.

approaches. In both cases the systems appear to have been approaching the same maximum removal efficiency. It may be that the recycling approach might require one additional extraction to reach the removal efficiency that was required with fresh solution.

Overall Soil Remediation Process

In this study, the procedures for soil sieving, soil decontamination, leachate treatment, and recycling were performed separately. However, conceptually these units can be combined together to create the overall soil washing process. A conceptual schematic diagram is presented in Figure 9. The first step of the cleaning system is soil preparation. Particles sizes ≤ 4.75 mm would be separated out of the system by a vibrating sieve. The second step of the process is to mix the soil with the sodium chloride solution in a blade washer in order to remove Pb from the soil. After contacting with the sodium chloride solution, the soil is then separated from the extracting solution by sedimentation and hydrocyclones. The extracting solution is then treated with Na_2CO_3 for Pb precipitation and chloride regeneration. The

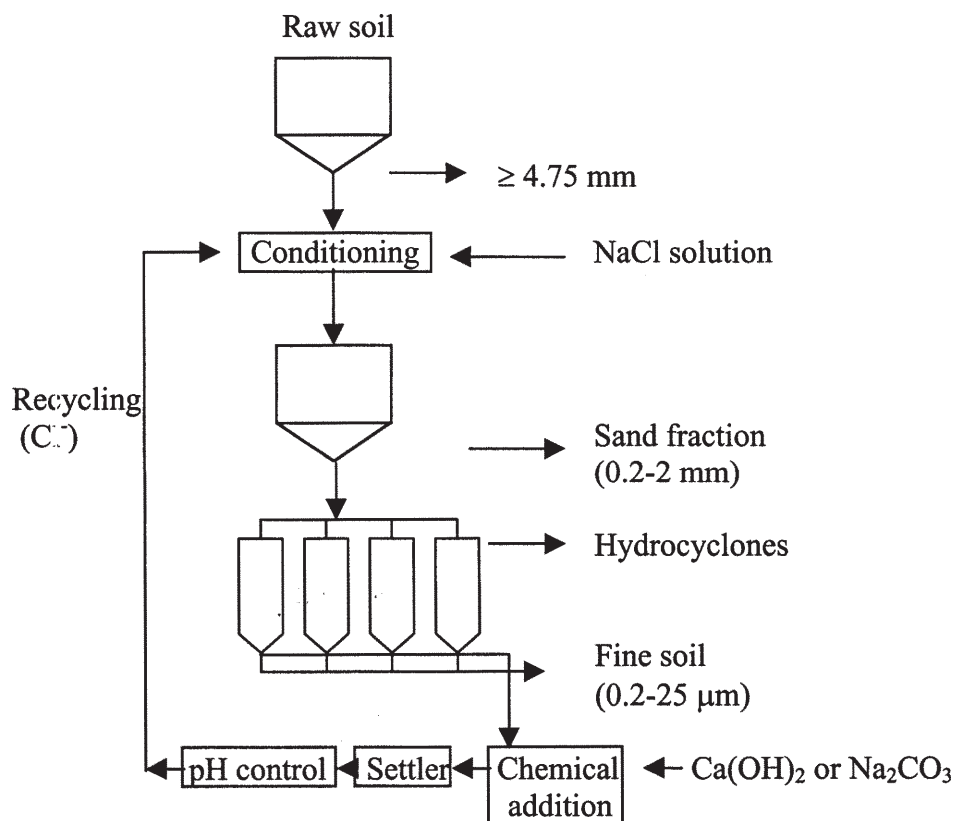


FIGURE 9

Schematic diagram for soil-washing process.

solution is passed through a settler to separate the precipitate and pH adjusted, if necessary prior to being returned to the washing stage.

SUMMARY

The following conclusions were arrived at from this study:

1. The removal of Pb after three sequential extractions with 8 M NaCl was found to be 83%, whereas only an average of 9% of the Ca was removed. With extrapolation from the Pb curve, higher removal efficiencies of Pb could be achieved if sufficient quantities of NaCl were added. For finer soil, six successive extractions removed 93% of Pb with a similar trend to the coarser soil.

2. An increasing trend of Pb removal was found as the liquid/solid ratio increased.
3. At a NaCl concentration of 8 M, the removal of Pb increased with the extraction time and approached 80% after 90 h. The experimental data were found to be well described by a first-order kinetic model.
4. The removal of Pb from the leachate was found to be 90, 99.7, and 35% with lime (25.2 g/L of leachate), sodium carbonate (4.48 g/L of leachate), and calcium carbonate (82 g/L of leachate), respectively. The removal efficiency of Pb was improved further when the pH was adjusted to 8.2 in the case of sodium carbonate.
5. Recycling the leachate after Pb removal using sodium carbonate resulted in 91% removal of lead from the coarser soil (≤ 4.75 mm) after six recovery cycles. Similar responses were observed for recycled extractants and fresh NaCl solutions.

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