

Influence of Acoustic Excitation on Effluent Concentration of Zinc from Clayey Soils

Aneel Kumar Hindu, Jiro Takemura, Agha Faisal Habib Pathan

Abstract—The efficiency of soil remediation techniques generally depends upon the contaminant sorption by soil and contaminant desorption from soil. Sorption and desorption again depends upon the soil contaminant interaction. Generally the desorption of heavy metals from fine grained soils like clay is considered as lengthy and costly process, particularly under in-situ conditions. In this research acoustically enhanced column tests were performed to evaluate the influence of acoustics to desorb heavy metal contaminant like zinc from fine grained soils like clay, considering in-situ stress conditions. The test results show that the sorption of zinc remained significantly higher than that of desorption, application of acoustics increased the removal of zinc ions sorbed on solid phase of soil and optimum increase in effluent concentration achieved at 1.4 pore volume.

Index Terms—Heavy metal, clay, desorption, acoustics, column test.

I. INTRODUCTION

The efficiency of soil remediation techniques generally evaluated from two factors i.e. (i) the amount of contaminant removed from soil surfaces (ii) the time required to achieve the desired contaminant level. The removal of heavy metal from fine grained soils is lengthy and costly process. This is because (i) the heavy metals are generally non-degradable and, (ii) fine grained soils have high sorption and low desorption capacities. Consequently, the remediation techniques generally do not remain very effective to clean the fine grained soils contaminated with heavy metals. In addition if in-situ remediation is desired, low permeability of fine grained soils make the remediation process further difficult and less effective. Hindu et al. [1] utilized batch equilibrium tests to investigate the possible sorption and then desorption of zinc from illite and illite silica mixture. They observed almost no removal of zinc ions from illite and illite-silica mixtures (see Fig. 1) with sequential dilution. This confirms that the removal (desorption) of zinc from illite is not an easy task.

Hindu et al. [1]; Chung and Kamon [2]; Hindu [3]; Hwang et al. [4]; Kyllonen et al. [5]; Lim et al. [6]; Meegoda and Perera [7]; Meegoda and Veerawat [8]; demonstrated that the application of acoustics may be effective to remove the sorbed heavy metals like (Cd, Cu, Pb, Zn, etc) from disaggregated soils.

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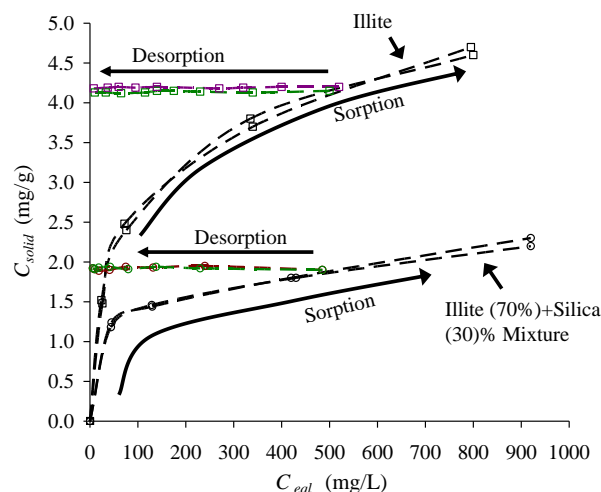


Fig 1: Sorption and Desorption of Zinc from Illite and Illite-Silica mixture [Hindu et al. [1]].

The application of acoustics may generate shock waves in liquid solid slurries. Shock waves can break or weaken the bond between solid and contaminant. The details of influence of acoustics in liquid, liquid solid slurries and in porous media can be referred in Hindu [3]. This research is motivated to examine the influence of acoustics to desorb the heavy metal contaminant from clayey soils considering in-situ stress conditions. For this purpose column tests were performed with and without acoustic excitations.

II. TEST MATERIALS

Test soil was the mixture of 30% clay (Illite) and 70% sand (silica 6). The properties of clay and sand are mentioned in Table I and Table II respectively. Zinc is selected as a heavy metal contaminant.

Table I. Properties of Illite Clay

Specific gravity	2.73
Liquid limit	60
Plasticity Index	30
CEC (mEq/100 g)	36.2
pH (10 g of soil/20 ml DDW)	6.67

Table II. Properties of Silica Sand 6

Specific gravity	2.65
C_u	2.12
C_c	0.965
e_{max}	1.13
e_{min}	0.67



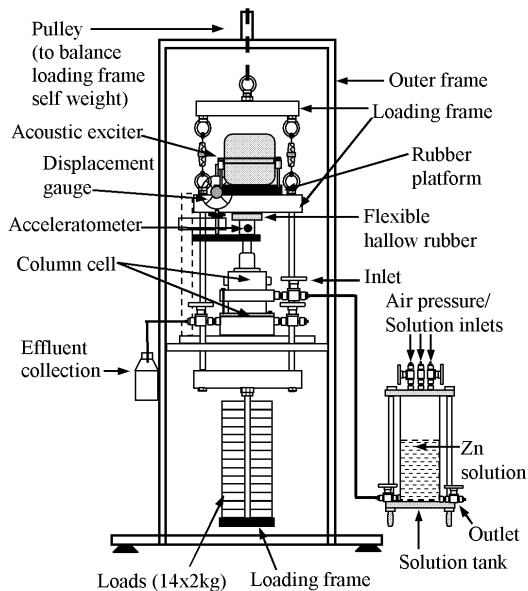


Fig: 2(a) Test Setup

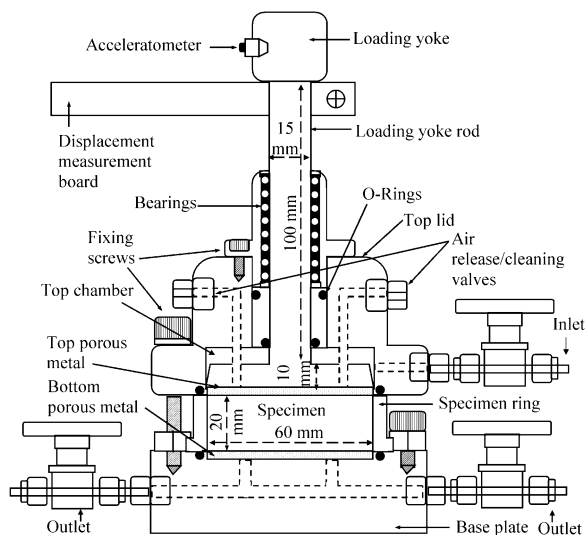


Fig: 2 (b) Column Cell

Fig 2: Test Setup and Column Cell

III. TEST SETUP

A column test setup (Fig. 2a) is purposely designed and fabricated for this research. It mainly consist of a column cell (Fig. 2b), loading system, acoustic exciter and solution tank.

The test set up is capable of creating well controlled conditions in the specimen like vertical effective stress, seepage stress and acoustic excitation (frequency, power and excitation time). The initial height of the specimen can be varied between 2 cm to 4 cm with fixed diameter of 6 cm. The acoustic excitation, vertical load and seepage load are applied from top to bottom of the specimen. The acoustic exciter is capable of generating acoustic frequency between 10 Hz to 10 kHz with power level up to 275 W and excitation time of 18 hrs in maximum. The maximum load carrying capacity of loading hanger is 28 kg.

IV. EXPERIMENTAL METHODOLOGY

50 kPa pre-consolidated block soil samples were obtained from soil slurry having initial water content of 2 times the

liquid limit of test soil. Deionized water (DW) was utilized to make the soil slurry. The 50 kPa pre-consolidated soil were then carefully inserted into specimen ring of 2 cm height and 6 cm diameter. Specimen was then further consolidated with 100 kPa vertical pressure and 20 kPa seepage pressure. The deionized water (DW) was utilized throughout the test to make the specimen saturated.

After that, DW was replaced with zinc contaminated solution of 500 mg/L (influent). The zinc solution was seeped through the specimen unless and until the effluent concentration (C) become equals to the influent concentration (C₀). The effluent concentration was determined at regular intervals (Pore volumes, PV). The Pore volume (PV) was calculated by utilizing (1) and (2). The normalized breakthrough curve which represents the relationship between C/C₀ and pore volume was obtained in the contamination process (sorption process) (Fig. 3). After confirming C= C₀, it was supposed that equilibrium condition was achieved.

$$PV = \frac{\text{Total volume of effluent}}{\text{One pore volume}} \tag{1}$$

$$\text{One pore volume} = ALn \tag{2}$$

Where A cross sectional area of specimen, L= Length of specimen and n= porosity of specimen

After achieving the equilibrium condition the contaminated solution was replaced with DW. The DW was then seeped through the contaminated soil to decontaminate the soil. The breakthrough curve in the decontamination process (desorption process) was also obtained (Fig. 3). Initially the effluent concentration decreased sharply. After that the rate of decrease in effluent concentration were significantly reduced (Fig. 3).

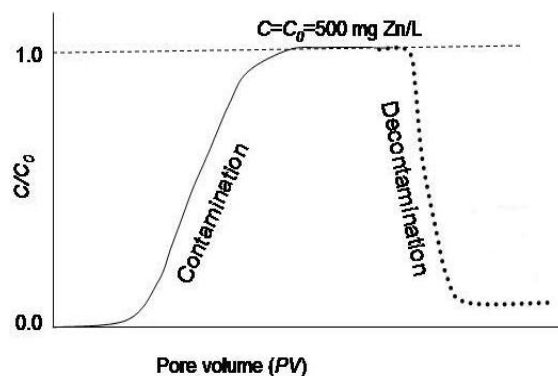


Fig 3: Breakthrough Curves in Contamination (Sorption) and Decontamination (Desorption) Processes of Zinc from Illite-Silica Mixture.

To observe the effects of acoustics in desorption, two column tests namely Test A and Test B were performed. In Test A no acoustic excitation was applied through out the test. While in Test B the acoustic excitation was applied at the start of decontamination process. The excitation was continued for 18 hrs with 9 kHz frequency and 275 W power level. The maximum acceleration was observed at frequency of 9 kHz. The effects of acoustics on desorption of contaminant were then observed.

V. RESULTS AND DISCUSSIONS

A. Breakthrough curves in contamination (sorption)

Fig. 4 shows breakthrough curves in sorption process for columns tests A and B. For both the tests the equilibrium condition was achieved at $PV \approx 45$. The $0.5 C/C_0$ is achieved at $PV \approx 21$. This shows the sorption behavior of both tests remained considerably identical. Hindu and Takemura [9] demonstrated that $0.5 C/C_0$ can be approximately considered as the retardation factor for illite and illite silica mixtures.

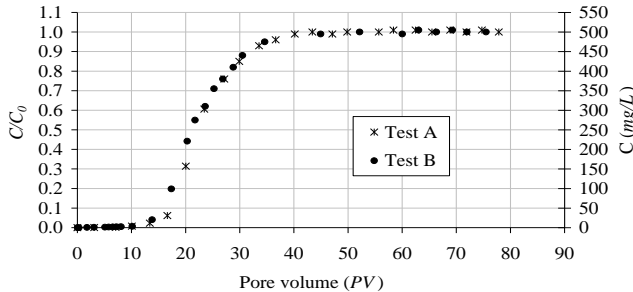


Fig 4: Breakthrough Curves in Sorption Process

B. Breakthrough curves in decontamination (desorption)

Fig. 5 shows breakthrough curves in desorption process for initial 10 PV. Solid marks on the curve of Test B are the effluent concentrations taken during the application of acoustics that was applied for 18 hrs ($PV \approx 3.5$). Hollow marks on the curve of Test B represent the effluent concentration without application of acoustics. No acoustic was applied for Test A. For Test A, effluent concentration remained almost the same as that of influent concentration for $PV \approx 0.5$. Then it was gradually decreased up to $PV \approx 1.0$. Afterwards, it sharply decreased up to $PV \approx 2.0$. From Test B, it is seen that the excitation caused the increase in effluent concentration than that of influent concentration ($C_0 = 500$ mg/L). The effluent concentration gradually increased to 550 mg/L at $PV \approx 0.5$. Then it was gradually decreased and reached to the 500 mg/L at $PV \approx 1.0$. Afterwards the effluent concentration were sharply decreased up to $PV \approx 2.0$. The increase in effluent concentration than that of influent concentration may be due to application of acoustics which caused the possible removal of Zn ions sorbed on solid phase. The sorbed Zn ions may not be removed in Test A i.e. without application of acoustics.

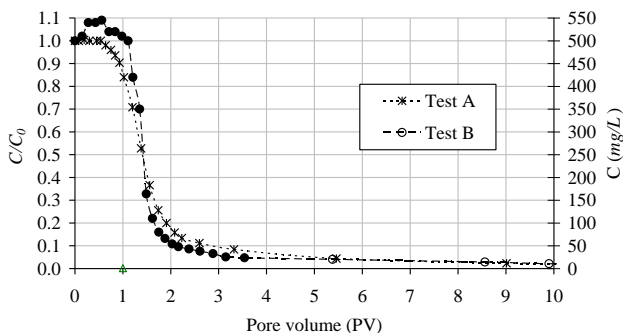


Fig 5: Breakthrough Curves in Desorption Process for Initial 10 PV.

For both the test cases $0.5 C/C_0$ was achieved at $PV \approx 1.5$. This indicates the amount of zinc getting desorbed from the solid surface. In sorption process $0.5 C/C_0$ was achieved at $PV \approx 21$ (Fig. 4). Thus it can be said that the sorption of zinc remained significantly higher than that of desorption.

The time is one of the key factors in the remediation of in-situ soils. The time of remediation to achieve the desired

concentration level may be reduced if the hydraulic conductivity of soil, seepage velocity and effluent concentration can be increased. Hindu [3] demonstrated that the application of acoustics has no significant effect on the hydraulic conductivity and seepage velocity of soil column. The change in effluent concentration (ΔC) is obtained by (3).

$$\Delta C = C_{acoustics} - C_{no-acoustics} \quad (3)$$

where $C_{acoustics}$ is effluent concentration during application of acoustics and $C_{no-acoustics}$ is the effluent concentration without application of acoustics.

Fig. 6 shows the change in effluent concentration (ΔC) for $PV \approx 3.5$. $C_{acoustics}$ was obtained from Test B and $C_{no-acoustics}$ was obtained from Test A (Fig. 5). A pore volume for Test A was 16 cm^3 of effluent volume while for Test B it was 16.2 cm^3 of effluent volume. In the Fig. 6, the PV of Test A is utilized. Accordingly, effluent concentration of Test B was adjusted. It is seen that the change in effluent concentration initially increased with increase in the $PV \approx 1.4$ and then it gradually decreased. Thus it may be said that the optimum application of acoustics may be up to $PV \approx 1.4$. It can also be presumed that the application of acoustics can decrease the treatment time to obtain the desired concentration level.

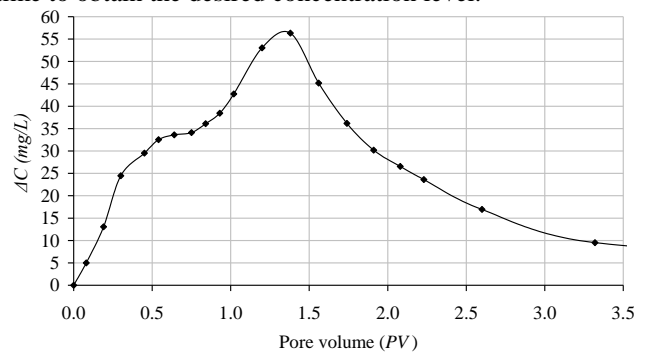


Fig 6: Breakthrough Curves in Desorption Process for Initial 3.5 PV

C. Tailing effect in decontamination (desorption)

Figure 7 shows tailing concentration for the column tests. It can be seen that for both the tests zero effluent concentration can not be achieved even though the seepage of DW was continued for $PV \approx 155$. This indicates the amount of zinc continuously desorbed from the solid surface. The higher tailing concentration of effluent in case of Test B can be related to the influence of the acoustics. The application of acoustics can break or weaken the bond between contaminant and solid phase [Hindu et al. [1]; Chung and Kamon [2]; Hindu [3]; Hwang et al. [4]].

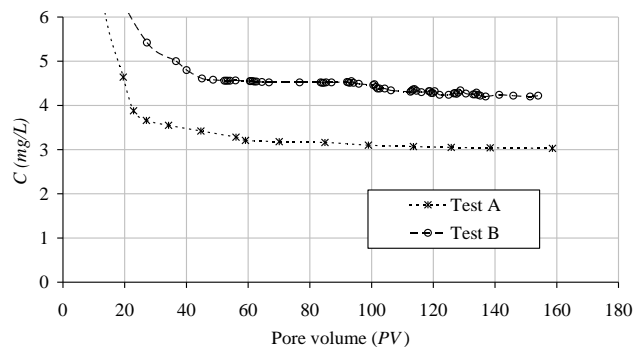


Fig 7: Tailing Effect in Desorption Process

VI. CONCLUSION

After achieving the equilibrium conditions in the sorption process of soil column, the application of acoustics were applied along with the seepage of deionized water (DW) to clean the soil column. The application of acoustics increased the effluent concentration than that of equilibrium concentration (influent concentration in sorption process). For seepage of DW without application of acoustics, effluent concentration never increased than that of equilibrium concentration. Thus it can be said that application of acoustics desorbed the contaminant from solid phase which may not be removed without application of acoustics.

The difference of effluent concentration during application of acoustics and effluent concentration without application of acoustics for the same pore volume is termed as change in effluent concentration. The change in effluent concentration increased up to $PV \approx 1.4$ and then it gradually decreased. Thus it may be said that the optimum application of acoustics may be up to $PV \approx 1.4$.

The tailing concentration for the acoustically treated test remained higher than that of test without application of acoustics. This indicates that the application of acoustics can weaken the bond between soil and contaminant for long time.

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