Desorption and retention of cadmium and phenol contaminants in single and combined systems in cement-based stabilization/solidification

V.R. Ouhadi[1, *], Dorsa Saaedifar[2], Ali Aalifar[2], and Zahra Akbari[3]
[1]Bu-Ali Sina University, Hamedan, Iran, and Adjunct Prof., School of Civil Engineering, University of Tehran, Tehran, Iran
[2]M.Sc. Student of Environmental Engineering, University of Tehran, Tehran, Iran
[3]Academic Member, School of Civil Engineering, University of Tehran, Tehran, Iran

*vahidouhadi@basu.ac.ir

Abstract

One of the suggested techniques to prevent the spread of contaminants in the soil is cement-based stabilization/solidification. The production of hydration products and the attainment of an alkaline pH are the two primary processes in this method. In natural conditions, contaminants enter the soil simultaneously and in combination with each other. The simultaneous presence of organic and heavy metal contaminants alters how the soil-cement system interacts with each contaminant. The objective of this study is to compare the desorption and retention amounts of cadmium and phenol separately and simultaneously in cement-based stabilization/solidification. In this context, the TCLP test has been used to assess the desorption amounts of phenol and cadmium, as well as their retention capacity in single and combined systems. An X-ray diffraction test was also carried out to examine the microstructure of the stabilization/solidification process. The results indicate that the retention percentage of phenol in the presence of cadmium did not differ much compared to the single system, while the amount of cadmium retention decreased in the presence of phenol. In a combined system, the simultaneous presence of phenol and cadmium causes a reduction in the intensity of the C-S-H peak compared to single systems. However, the presence of cadmium had a greater effect on reducing the intensity of the C-S-H peak than phenol. Furthermore, in the presence of cadmium, the amount of phenol extracted during the TCLP test has increased compared to the single system.

Keywords: Cadmium, Phenol, Bentonite, Stabilization/Solidification, TCLP.

Introduction

Organic pollutants in nature degrade with difficulty, remaining in soil or groundwater sources for decades or even centuries, posing a serious threat to human health and the environment. Phenolic compounds, considered as organic pollutants, are highly detrimental to human health and other living organisms at low concentrations, categorizing them as hazardous contaminants. These compounds are produced from industries such as petroleum, petrochemicals, and coal extraction, extensively used in the production of many resins, including phenolic resins [1]. On the other hand, in recent years, pollution caused by cadmium has become a major concern due to its widespread use in industries such as metal plating and nickel-cadmium batteries [2].

Despite numerous studies conducted on the stabilization/solidification of pollutants using cement, the investigation of this process in the presence of heavy metals and less attention to organic compounds has been noted. According to the EPA standard, cement-based solidification is recognized and introduced as the most common method to combat pollution transfer. The aim of this study is to compare desorption and retention levels of cadmium and phenol separately and simultaneously in the cement-based stabilization/solidification method.

Materials and Methods

For this study, bentonite soil predominantly containing montmorillonite minerals was used. This clay soil, due to its unique properties such as high specific surface area, can adsorb high concentrations of contaminants, making it widely used in composite covers and geo-synthetics clay liners (GCL) in landfills. Additionally, Portland cement Type II was used for the stabilization/solidification process. The chemical substances used in this study included cadmium heavy metal in the form of nitrate salt ($Cd(NO_3)_2.4(H_2O)$) and phenol organic compound (C_6H_5OH).

To calculate the adsorption and retention capacity of bentonite soil and 10%, 30%, and 50% cement-containing bentonite in systems containing only cadmium or phenol (single-component systems), a batch equilibrium test was performed. For this purpose, aqueous solutions of cadmium heavy metal were prepared at concentrations of 10, 20, 50, 100, 150, 250, 350, and 500 cmol/kg-soil. These concentrations were selected based on previous studies in the field of heavy metal stabilization/solidification. Phenol aqueous solutions were prepared at concentrations of 50, 100, 150, 250, 500, 700, 1000, and 1500 mg/l. Phenol concentrations were chosen based on reported concentrations of this organic compound in landfill leachate (between 0.003 to 17 mg/l) [3] and concentrations studied in previous research (between 25 to 2000 mg/l) [4]. In batch equilibrium experiments in systems containing phenol and cadmium (two-component systems), aqueous solutions of phenol and cadmium, separately prepared, were combined in equal amounts ranging from low to high concentrations. Then, as mentioned, the solution was added at a rate of 30 ml to 1.5 grams of soil or soil-cement mixture, and the batch equilibrium test was performed.To evaluate the desorption of stabilized and solidified contaminants under weak acidic conditions, the TCLP test was conducted according to the method provided by EPA-1311 [5].

Results and Discussion

The relationship between the adsorption and retention levels of phenol based on its initial concentration along with pH changes in bentonite mixtures with different cement contents is shown in Figure 1. As the concentration increases, the dielectric constant decreases (resulting in a decrease in the double-layer thickness), reducing the adsorption due to hydrogen bonding. The adsorption and retention levels of phenol are also influenced by the amount of organic contaminant added to bentonite. It is worth mentioning that the pH of all samples without cement was approximately 9; therefore, pH had the same effect on adsorption and retention of this contaminant at different concentrations.

According to Figure 1, the adsorption and retention levels of phenol by cement-free bentonite at concentrations of 250 and 500 mg/l were 48 and 77 mg/kg, respectively, and the adsorption and retention percentages for these samples were 19% and 15%, respectively. Adding cement introduces two mechanisms of stabilization and solidification affecting phenol retention. With increasing cement content, despite the increase in pH compared to cement-free bentonite, phenol adsorption and retention improved. With the addition of 10% cement to bentonite, phenol adsorption and retention increased by approximately 7.5%. Similarly, with the addition of 30% and 50% cement, these levels increased by approximately 12% and 17%, respectively, compared to cement-free samples, indicating that the efficiency of the stabilization/solidification method has increased with increasing cement content.

Furthermore, it is observed that at low phenol concentrations, increasing cement slightly increased the adsorption and retention levels; however, the difference in adsorption and retention levels with increasing cement at high concentrations is significant. It can be concluded that for the removal of phenol from contaminated environments with low concentrations, the use of low cement percentages is more cost-effective.

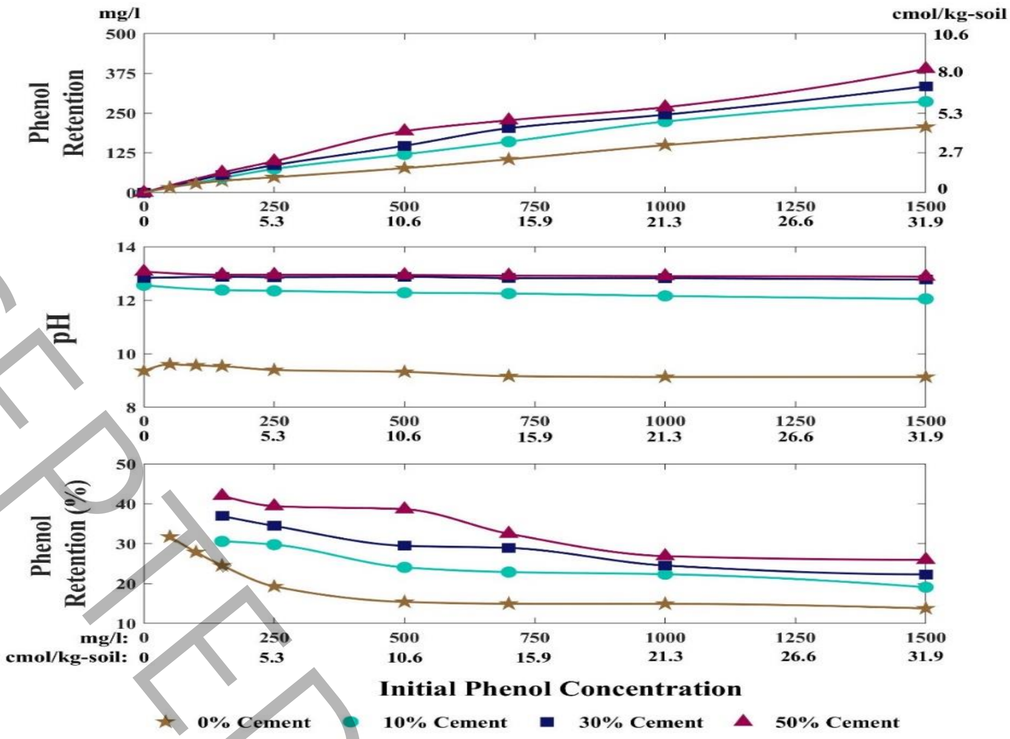

Figure 1: Pattern of phenol adsorption and retention levels along with pH changes for bentonite with different cement percentages.

Conclusion

-In the adsorption and retention capacity determination test, the pH of cement-free and cement-containing samples in two-component states decreased due to the presence of cadmium compared to single-component samples containing only phenol. The percentage of adsorption and retention of phenol in the two-component state without cement increased slightly due to the pH decrease compared to the single-component state. However, in the two-component state with cement, the presence of cadmium delayed hydration processes, causing phenol retention to be disrupted due to the solidification mechanism, but overall, due to the pH-dependent adsorption of phenol, the retention percentage of phenol in this state did not differ much from the single-component state.

-In cement-free and cement-containing samples in the two-component state, the adsorption and retention levels of cadmium decreased due to the addition of phenol and pH changes compared to the single-component state. The maximum adsorption and retention of cadmium by cement-free bentonite were 38 cmol/kg-soil, which decreased compared to the single-component state with a level of 62 cmol/kg-soil. This decrease is due to the presence of phenol and the reduction in double-layer thickness resulting from the decrease in the dielectric constant of the permeating fluid.

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