Effectiveness of Inorganic Amendments in Immobilizing Containminants in Sewage Sludge

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Abstract: Sewage sludge is inevitable end by-product of sewage treatment. Land application provides a cost-effective alternative for sewage sludge disposal. However, the release of contaminants from sewage sludge amended soils is a major source of water quality impairment. Therefore, sewage sludge immobilization seems necessary. In this work, red mud and lime were explored to immobilize the contaminants of sewage sludge. The results showed that red mud and lime could reduce the contaminants release. The results of XRD showed that there were no detectable changes in the mineralogy of sewage sludge after chemical amendments. EDX spectra of many red mud amended sewage sludge particles contained large Al peaks and lime amended sewage sludge particles contained large Ca peaks, while untreated sewage sludge particles showed little Al and Ca.

Keywords: Sewage sludge; Red mud; Lime; Phosphorus; Heavy metals

1. Introduction

Sewage sludge is an inevitable end by-product of sewage treatment. Land application provides a cost-effective alternative for sewage sludge disposal. However, sewage sludge contains high content of phosphorus and heavy metals that may limit its application. The release of contaminants from sewage sludge amended soils is a major source of water impairment. Therefore, contaminants immobilization before sewage sludge land application seems necessary.

Recently, there has been considerable interesting in developing management practice that enhances the ability of soils to retain contaminants such as phosphorus and heavy metals. Soil amendments including zeolite [1,2,3], gypsum [4], bentonite [5] and phosphate based fertilizers [6] can be able to improve the sorption properties of soils, hence reduce the contaminants release to the surrounding environment.

The feasibility of employing amendment to reduce containminants release will to a great extent depend on the cost and availability of the materials. Lime is a conventional amendment for phosphorus and heavy metals immobilization [7,8]. Red mud is the residue of aluminum industry. Because of its relatively large surface area and high content of iron, aluminum, calcium oxides and hydroxides, Red mud can be considered as a cost-effective material for phosphorus and heavy metals adsorption and immobilization [9,10,11,12,13,14,15]. Although the immobilization of phosphorus and heavy metals using lime and red mud amendments in soils has been successfully demonstrated in many studies, there have been few reports on the investigation of phosphorus and heavy metals immobilization in sewage sludge by lime and red mud. Therefore, the present study focused on phosphorus and heavy metals immobilization in sewage sludge by red mud and lime amendments.

2. Materials and Methods

2.1. Materials

Sewage sludge was obtained from Xiao Hongmen sewage treatment plant, located at Chaoyang District, Beijing. Lime was of analytical reagent grade. RM used in this study was obtained from Shandong Branch, Aluminum Corporation of China, which was air dried, crushed and sieved to pass a 2 mm sieve prior to use. The composition and properties of RM were listed in Table 1[16].

2.2. Incubation Experiments

As for the immobilization experiments, 1000g sewage sludge was thoroughly mixed with red mud and lime at prescribed mass ratio and then the mixtures were incubated in the dark at 25℃ for 3 days. After the incubation process was completed, the incubated samples were air dried, milled to pass a 2 mm sieve and stored in closed dark bottles for further investigation.

Table 1. Composition and properties of red mud.

Composition	*Contents (w/w, %)*
SiO_2	12.45
Fe_2O_3	25.68

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Al_2O_3	10.98
CaO+ MgO	13.88
Na_2O	5.76
K_2O	0.33
TiO_2	12.94
Loss on ignition	15.41
pH	12.55
Specific surface area (m^2/g)	16.48
Crystalline phases	Hematite, Bayerite, Calcite, Cancrinite, Goethite, Rutile and Quartz

2.3. Leaching Experiments

Incubated samples were extracted with de-ionized water. Un-treated and treated sewage sludge samples were extracted with de-ionized water to determine the release of contaminants from the sewage sludge. 1.0 g of incubated samples were weighed into 50 ml centrifuge tube and agitated for 1 hour with 10 ml de-ionized water, the tubes were then centrifuged at 10000 rpm for 10 min. Unfiltered samples were colleted for measurement of pH and electrical conductivity（EC）. Filtered samples were colleted for measurement of phosphorus and heavy metals.

2.4. Analytical methods

The pH and electrical conductivity (EC) values of the amended sewage sludge were measured in slurry at a solid/solution ratio of 1:2.5 in accordance with International Soil Association Method. The moisture content of the soil was calculated according to the mass difference before and after the sewage sludge being dried in an oven at 105℃ for 24 h [17]. Organic matter content of the sewage sludge sample was determined using the loss-on-ignition method [18]. Phosphorus concentration was analyzed by the phosphomolybdate blue method of Murphy et al and Riley et al [19,20]. For the total element analysis, the sewage sludge was digested using concentrated nitric acid, hydrofluoric and perchloric acid according to Sterckeman et al. [21], then the total element concentrations were analyzed using an inductively coupled plasma atomic emission spectroscopy (ICP-AES, Prodigy).

The micrograph and microanalysis of the samples were determined using a 30 kV HITACHI S-3000N scanning electron microscope (SEM). Mineralogical constituents of samples were determined using X-ray diffractometry. The analysis was performed in a Rikaku TTR-III diffractometer at room temperature, with Cu Kα radiation at a scan speed range of 0.2°S^{-1}. The XRD patterns were recorded in the 2θ range of 10-90°.

3. Results and Discussion

3.1. Sewage Sludge Characteristics

The main physical and chemical properties of sewage sludge are presented in Table 2. From this table, it can be seen that the pH and EC value of sewage sludge was 7.13 ±0.05 and 1,042±68 μS/cm, respectively. In addition, sewage sludge presented high moisture content, reaching up to 83±0.9 %. The total organic matter value was 497.0±0.4 mg/g. The total phosphorus content in the sewage sludge was 15.41±0.17 mg/g, implying that sewage sludge would be a rich source phosphorus when it was land applied. Meanwhile, it can be observed that the total concentrations of Cd, Zn and Pb in the sewage sludge were much lower than the pollutant concentration limits for land application of sewage sludge recommended by the USEPA. Zn was the predominant heavy metal contaminant in the investigated sludge.

Table 2. Selected properties of the samples.

Parameter	*Sewage sludge*
pH（1：20）	7.46±0.18
EC（μS/cm）	1,158±21
Moisture content (%)	83.0±0.9
Total organic matter (mg/g)	497.0±0.4
Total P(mg/g)	15.41±0.17
Total heavy metals (mg/kg)	
Cu	281±43
Zn	978±16
Cd	7±1
Pb	123±7
K	1,128±58
Na	1,880±32
Fe	4,784±44
Mn	154±4.0

Sequential chemical extraction experiments were shown in Fig. 1 and Fig. 2. Sequential chemical extraction experiments indicated that heavy metal speciation was different for Cd, Zn and Pb in the investigated sewage sludge. Zn was observed mainly in the organic matter and residual fractions, while in contrast, Cd and Pb were observed mainly in the organic matter and carbonate fractions.

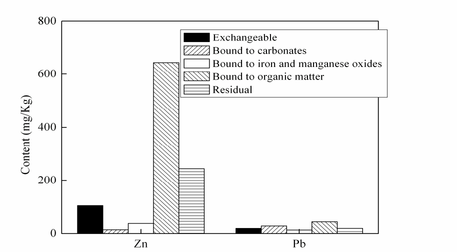

Figure 1. Zn and Pb speciation.

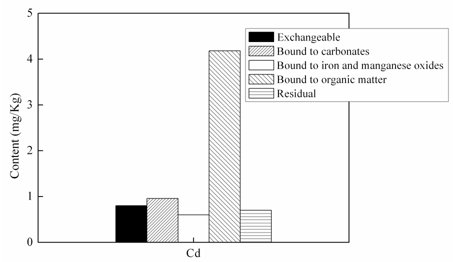

Figure 2. Cd speciation.

3.2. Batch Leaching Experiments

In order to optimize the mass ratio of amendments to sewage sludge and evaluate the amendments on contaminants immobilization, sewage sludge amended with amendments at mass ratio of 1, 3, 5, 7 and 10% were investigated by batch leaching experiments. The results were shown in Fig. 3. It is clearly shown in Fig. 1 that red mud and lime amendments significantly reduced phosphorus release from the amended samples. In the un-amended sewage sludge, the phosphorus release was 237.0 ± 21.5mg/Kg, while in the red mud and lime amended sewage sludge, the phosphorus release was reduced from 94.0±26.7 and 8.0±1.6 mg/Kg to 5±0.8 and 0 mg/Kg, respectively.

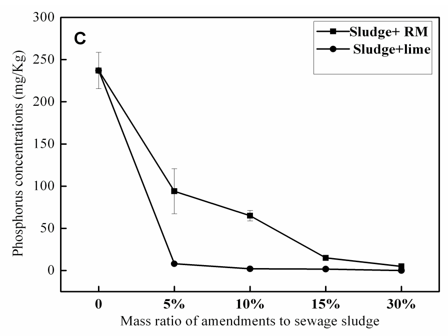

Figure 3. Phosphorus concentrations in the un-amended and amended sewage sludge.

For the heavy metals in the red mud amended sewage sludge, the results were shown in Fig. 4. It is clearly shown in Fig. 4 that red mud significantly reduced heavy metals release from the amended samples. The immobilization efficiency increased as more amendments were used. When sewage sludge mixed with 5% red mud, the amount of leached Cd, Zn and Pb was reduced from 0.07, 65.82, and 2.94 mg/Kg to 0, 9.40 and 1.11 mg/Kg, respectively. The immobilization efficiency of Cd, Zn and Pb was 100, 85.7 and 62.2%, respectively.

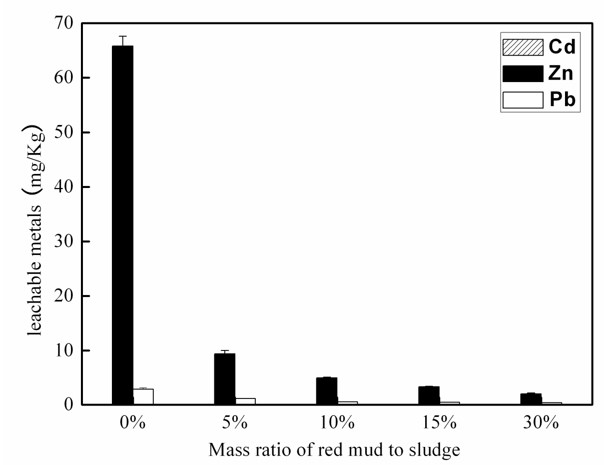

Figure 4. Heavy metal concentrations in the red mud amended sewage sludge.

For the heavy metals in the lime amended sewage sludge, the results were shown in Fig. 5. The leaching of heavy metal concentrations in the lime amended sewage sludge has similar trends in the red mud amended sewage sludge. Red mud and lime amendments at 10% significantly reduced the water extractable heavy metals, which is comparable with that at 15% of red mud and lime amendments. Similar results have been observed for phosphorus immobilization. As a compromise between the immobilization efficiency and amendment cost, 10% red mud and lime amendments were chosen as the amendment ratio for the next experiments.

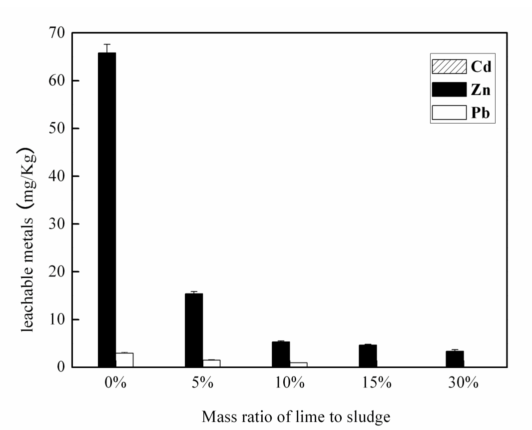

Figure 5. Heavy metal concentrations in the lime amended sewage sludge.

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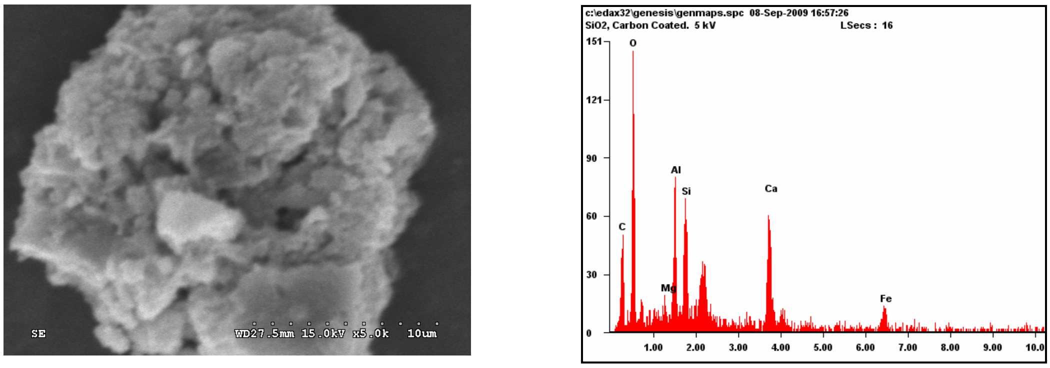
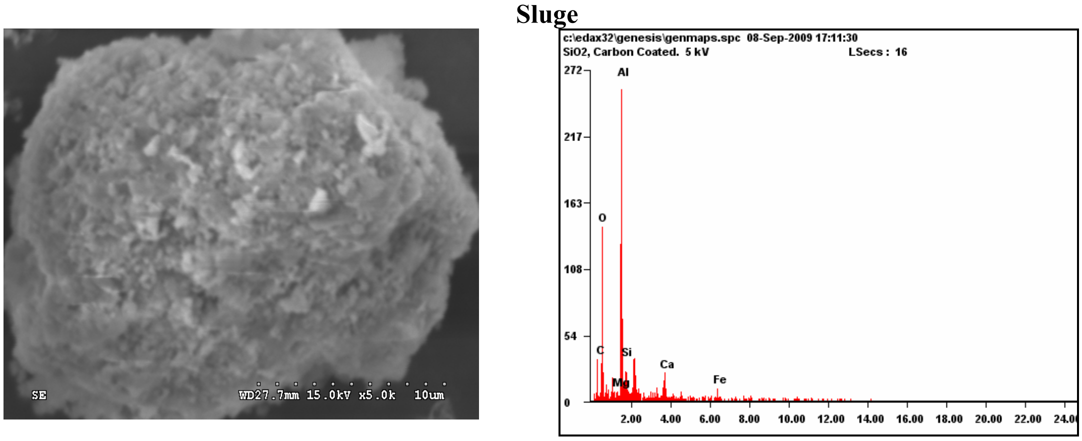
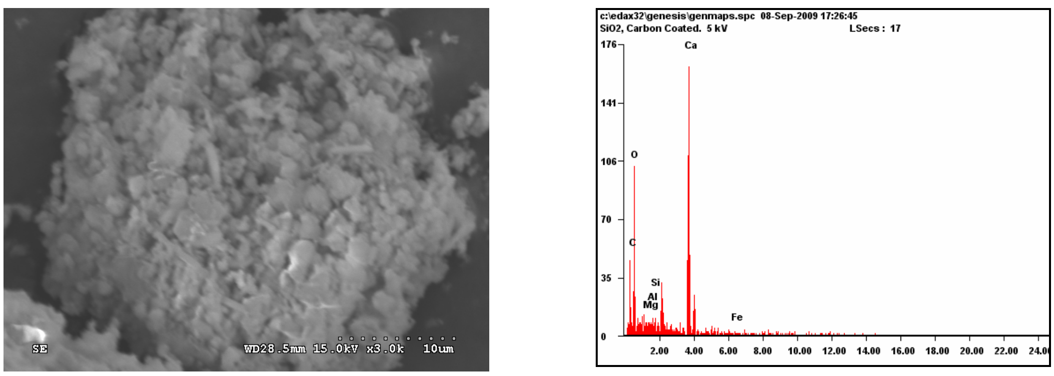


Sluge



Sludge +10% red mud



Sludge +10% lime

Figure 7. SEM of un-amended and amended sluge.

3.3. SEM and XRD

Based on the above results, 10% red mud and lime amended sewage sludge was selected for the SEM and XRD analysis. The results of SEM and XRD analysis were shown in Fig. 6 and Fig. 7. The Comparison of the powder XRD patterns of the un-amended and amended sewage sludge showed that there were no detectable changes in the mineralogy of sewage sludge after chemical amendments. Likewise, SEM analysis of treated soils also showed no any obvious differences in trace mineral phases after amendment. Overall, no newly-formed phases were detected in any of the amended sewage sludge by XRD and SEM analytical techniques. However, EDX spectra of many red mud amended sewage sludge particles contained large Al peaks and lime amended sewage sludge particles contained large Ca peaks, while untreated sewage sludge particles showed little Al and Ca.

4. Conclusions

This study examined the potential of using red mud and lime in reducing the release of phosphorus and heavy metals such as Cd, Zn and Pb from sewage sludge to the environment. The results showed that water soluble phosphorus and heavy metals were effectively controlled by a wild range of red mud and lime. The results of SEM and XRD analysis showed that there were no detectable changes in the mineralogy of sewage sludge after chemical amendments.

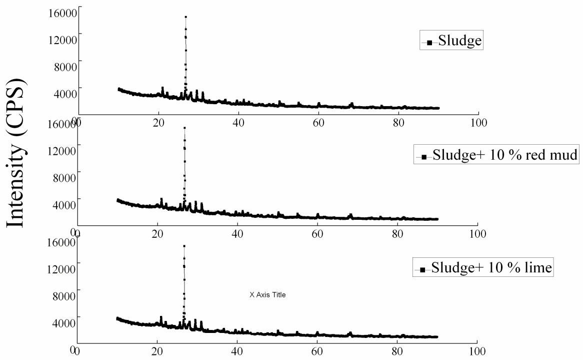


Figure 6. XRD of un-amended and amended sluge

5. Acknowledgements

Financial support provided by the Public Industry Research for National Environmental Protection (under Grant No. 200709037), National Water Pollution Control and Management Technology Major Projects (under Grant No. 2009ZX07104-005), and the National High Technology R&D Program (863) from Ministry of Science & Technology of China (under Grant No. 2007AA06Z344 and 2008AA06A409-3) is gratefully acknowledged. The provision of red mud by Research Institute of Shandong Branch, Aluminum Corporation of China was greatly appreciated.

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