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Treatment of abandoned coal mine discharged waters using lime wastes

Jae E.Yang *Division of Biological Environment, Kangwon National University, Chunchon, Korea*
Hee Joung Kim *Department of Environmental Sciences, Kangwon National University, Chunchon, Korea*
Yong-Sik Ok *Division of Biological Environment, Kangwon National University, Chunchon, Korea*
Jai-Young Lee *Department of Environmental Engineering, University of Seoul, Seoul, Korea*
Joonhong Park* *Department of Civil and Environmental Engineering, Yonsei University, Seoul, Korea*

ABSTRACT: We evaluated the feasibility using waste lime for reclaiming abandoned coal mines. For this evaluation, lime wastes were reused in neutralizing coal wastes in a field experiment. In runoff and leachate, pH and heavy metals were monitored for approximately 4 months to evaluate ecotoxicity at the remediation site. When the amount of added lime cake was equivalent to the 100% lime requirement for neutralization, stable neutralization was obtained during the entire experimental period. Because of pH neutralization, ecotoxic heavy metals were efficiently contained in the coal waste pile. When smaller amounts of lime cake were applied, although heavy metal releases did not increase, the pH in runoff/leachate fluctuated depending on the amount of precipitation and the history of field treatment. This suggests that field specific environmental factors have to be considered in determining the amount of lime cake required for stable neutralization. These findings from the field study demostrated the potential use of lime waste from soda ash production for reclaming abandoned coal mines.

Key words: coal overburdens, acidic mine drainage, lime waste, mine remediation

1. INTRODUCTION

In Korea, over 300 coal mines have been closed or abandoned due to the depression of the mining industry since the late 1980s (KCIPB [Korea Coal Industry Promotion Board], 2000). Acid mine drainage (AMD) from these coal waste piles are discharging to streams, polluting soil and water environments. AMD leachate typically has low pH values and carries dissolved heavy metals at relatively high concentrations (Singer and Stumm, 1970; Choi et al., 1998; Hedin et al., 1994; Kim et al., 1999; Park et al., 2001; Park et al., 2002; Yang et al., 2002). When these dissolved metals are released from anoxic groundwater to oxic subsurface water, oxidized metals form precipitations, heavily coating riverbeds and soils (Eger, 1994).

KCIPB (2000) has spent over $15 million dollars annually to remediate abandoned coal mines, focusing on AMD leachate treatment and forest restoration. Calcite ($CaCO_3$) and crushed limestone have often been used as neutralizing agents for acidic wastewater treatments (Skousen and Ziemkiewicz, 1996; Skousen et al., 1990). In the case of calcite, however, its high cost hinders its field application. Because of their exothermal reactions with AMD and coal wastes, heat released from use of calcite/lime stone particles may result in destructive effects on soil microbial communities and plant roots. To circumvent these problems, we previously proposed the concept of using "lime cake," waste materials from Solvay soda ash production, because of its cost-effectiveness and non-exothermal reaction with AMD (Yang et al., 2002). In addition, recycling of the lime waste will be advantageous for increasing the life cycle of landfills where otherwise a large amount of lime wastes has to be disposed. In this work, we conducted a field study to evaluate the feasibility of using lime waste in remediation of abandoned coal mines. The specific goal was to collect long-term water quality data (pH and ecotoxic heavy metals) when an abandoned coal mine site was treated with recycled lime cake.

*Corresponding author: parkj@yonsei.ac.kr

2. MATERIALS AND METHODS

An abandoned coal mine site in Okgae (Kangwon, Korea) was selected for the field study. A coal waste pile at the site was separated into five sub-areas using plastic boundaries, and duplicate lanes were constructed in each sub-area (Fig. 1). Runoff and leachate were collected together in a water reservoir. Three pipes (5 cm in diameter) were buried and connected to the reservoir to collect the leachate. Each sub-area was treated with and without the lime waste. Waste lime cake was obtained from a soda ash manufacturing plant (Dong-Yang Chemical Inc.). Treatments included non-treatment control (coal waste only), $CaCO_3$ treatment, and lime cake treatments. According to the preliminary experiment, 24 kg of lime cake was required to neutralize one tone of coal waste (100% lime requirement [LR]). Three different amounts of lime cake (25, 50, and 100% LRs) were homogenized with coal wastes, and then covered with a 30 cm layer of topsoil. For $CaCO_3$ treatment, 13.8 kg of $CaCO_3$ was homogenized with one ton of coal waste, and covered with topsoil in the same manner. The chemical characteristics of the lime cake, coal waste, and topsoil are summarized in Table 1. Varions water quality paramcters including pH and heavy metals in the collected runoff/leachate were periodically measured for 4 months (from

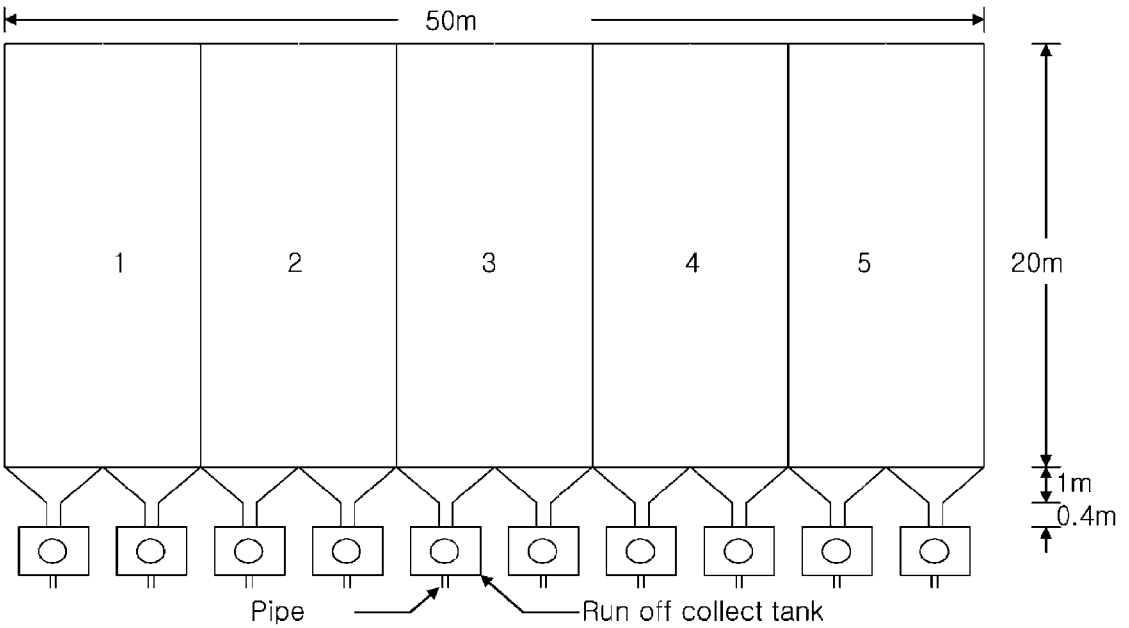

Fig. 1. Cross section (bird eye's view) of the field experimental system.

April 26 to August 26, 2004).

The elemental compositions of the coal waste and lime cake were analyzed using an X-ray fluorescence (XRF) method. Heavy metals (Mn, Cr, Cd, Cu, Pd, and Al) were analyzed as ecotoxicity indicators using an ICP-AES (inductively coupled plasma atomic emission spectrometer [Australia Latam 8440]). A 0.1 M HCl extraction method was used to remove heavy metals from the solid phase (lime waste and coal waste) prior to the analysis.

3. RESULTS AND DISCUSSION

3.1. Chemical Chacteristics of Coal Waste and Lime Cake

The coal waste was acidic (pH=3.5) and contained a low electrical conductivity (EC), while the lime cake had high values of Ca, Mg, K and Na along with high values of pH and EC. These results indicate that the lime cake is a good neutralizing agent for the acidic coal waste.

Heavy metals were also analyzed in both the lime cake and coal wastes. According to XRF analysis, Mn and Cr were not detected. This conclusion was confirmed by the following ICP-AES analysis with the HCl extraction. In the same samples, Cd was not detected. However, significant amounts of Cu, Pb, and Al were detected. Based upon these results, Cu, Pb, and Al were used as ecotoxicity indicators in the water quality evaluation in the following field experiment. Sr was not used as an ecotoxicity indicator in the field study, due to the fact that its ecotoxicity was not well established in literature, although the metal was present in the lime cake and coal waste samples.

3.2. Neutralization Evaluation

The low pH of coal waste rose up to 7.5 when mixed with either $CaCO_3$ or lime cake without topsoil. When mixed with topsoil, however, pH values in the collected runoff/leachate slightly decreased to approximately 6 (Fig. 2). This might be due to the pH buffer capacity of the topsoil. When 100% LR of lime waste was applied, all of the pH values

Table 1. Field experiment conditions.

Number (in Figure 1)	Treatments	Lime Treatment Methods
1	Coal waste only	
2	Coal waste + $CaCO_3$ + topsoil	Mixed
3	Coal waste + Lime cake (LR* 100%) + topsoil	Mixed
4	Coal waste + Lime cake (LR 50%) + topsoil	Mixed
5	Coal waste + Lime cake (LR 25%) + topsoil	Mixed

*LR indicates lime requirement.

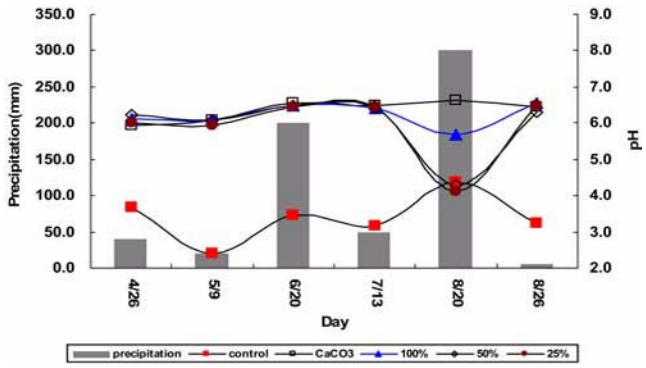

Fig. 2. Precipitation and pH in run-off and leachate.

remained above 5. When smaller amounts of lime wastes (25 and 50% LRs) were applied, however, a temporal decrease of pH values (lower than 5) was observed with a great amount of precipitation occuring at a late stage of the field experiment (8/20 data). This indicates that the smaller amounts of lime waste were probably insufficient for stable neutralization during the experimental period. One possible explanation for this is that the heavy rain had reached the deeper part of the waste coals, which might have been still acidic. These results show that the stability of neutralization with lime cake was influenced by the amount of lime cake, the distribution of local precipitation, and the history of treatment.

3.3. Heavy Metal Evaluation

In comparison to no-treatment controls, lime cake treatments reduced the concentrations of Cu, Pb, and Al in the runoff and leachate (Figs. 3, 4, and 5). Regardless of the amount of lime cake, these heavy metals were stably contained in their source. Efficiencies in containing the heavy

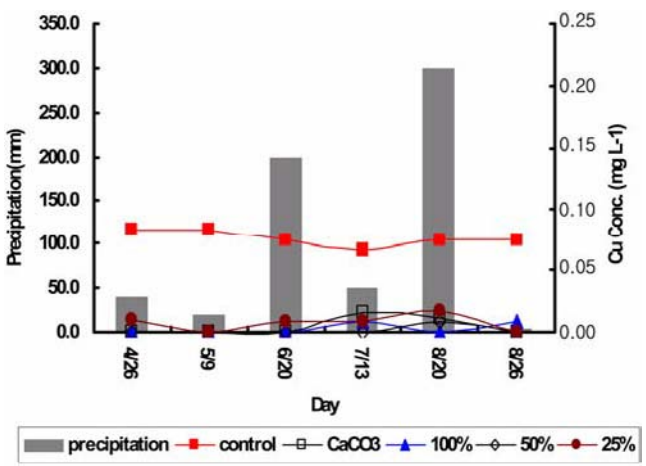

Fig. 3. Precipitation and copper (Cu) concentrations in runoff and leachate. The % numbers indicate the amount of lime cake as % LR.

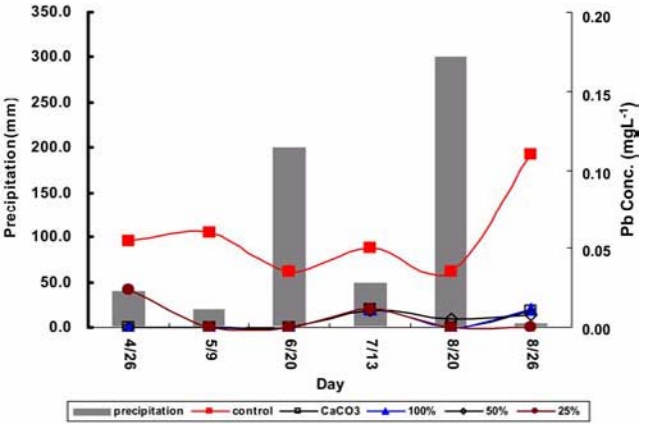

Fig. 4. Precipitation and lead (Pb) concentrations in runoff and leachate. The % numbers indicate the amount of lime cake as % LR.

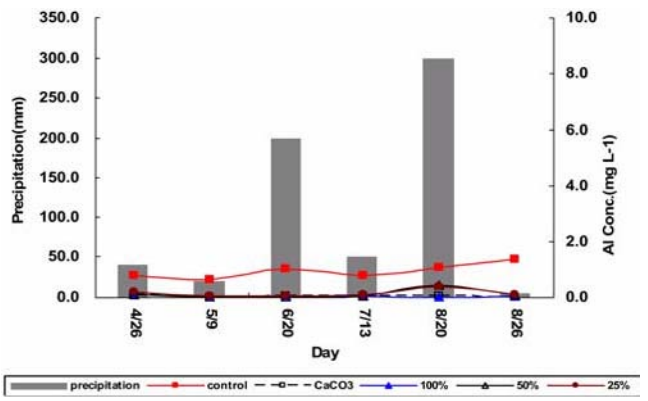

Fig. 5. Precipitation and aluminum (Al) concentrations in runoff and leachate. The % numbers indicate the amount of lime cake as % LR.

metals were similar between both reference (calcite) and test (lime cake) treatments. Because the heavy metal concentrations in the non-treated samples were relatively low, a further evaluation would be needed for higher heavy metal concentration cases.

4. CONCLUSION

This study evaluated the feasiblity of using of lime wastes for remediating abandoned coal wastes. Ecotoxic heavy metals were efficiently contained in their source. The improved containment of heavy metals may have been attributed to the solidification/stabilization of the metals via neutralization. When smaller amounts of lime cake were applied, acidic pH values were observed temporally with a great amount of precipitation occurring in a late stage of the field experiment. This suggested that field-specific environmental factors such as local precipitation and field treatment history have to be considered in determining the amount of waste lime required for a stable remediation performance.

Furthermore, a subsequential revegetation experiment at the same site illustrated that orchard grass could grow in the lime cake treated areas but not in the $CaCO_3$ treated areas (data not shown), suggesting that the use of the lime waste is more ecologically friendly. Considered together, the findings from this field study successfully demonstrated that lime waste from soda ash production can be reused for reclaiming abandoned coal mine area.

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