

Acid Mine Drainage Treatment of Overburden for the Removal of Cation Metals

Dyah Tjahyandari Suryaningtyas ^{a)}, Rudy Sayoga Gautama ^{b)}

^{a)}*Department of Soil Science and Land Resources, Bogor Agricultural University; Jl. Meranti, Darmaga Campus, Bogor-Indonesia 16680; email: DyahSuryaningtyas@yahoo.com*

^{b)}*Department of Mining Engineering, Bandung Institute of Technology; Jl Ganesa 10 Bandung-Indonesia 4025; email: r_sayoga@mining.itb.ac.id*

Abstract

This study reports a laboratory design of a process to remove metals from overburden (OB). A column study investigation was conducted to assess the influence of different simulated acid mine drainage (AMD) on several cations release of OB. The potential acid forming (PAF) material produced leachate pH as low as 3, while the non-acid forming (NAF) material elevated leachate pH, it was initially alkaline, increased above 7. Dissolution of silicate minerals such as plagioclase was adequately rapid to neutralize most of the acid produced at the resultant low rate of iron sulfide oxidation. According to cumulative leaching curves, the relative mobilities of the different elements in there as follows $Fe^{+3} > Mg^{+2} > Al^{+3} > Cu^{+2}$.

Key words: acid mine drainage, metal, topsoil substitute

Introduction

Natural topsoils are often more difficult to use and less desirable than alternative spoil materials. Natural topsoils often are typified by acidic, infertile and/or shallow. Removing and replacing nature topsoils are often impractical. Those make natural soils unsuitable for reclamation and revegetation. It is therefore the application of topsoil substitutes derived from overburden (spoil) is become an alternative choice.

Regarding to overburden as a topsoil substitute, many studies have been focused on the nature and rate of mine spoil morphology, chemical, physical, and genesis to determine which mine spoils are suitable as topsoil substitute. As plant growth medium, mine spoils in general have several disadvantages, including physical, chemical, and biological properties. Particularly in chemical properties, mine spoils are often extremely acidic (pH < 4) due to pyrite oxidation and sulfate weathering which is called sulfurization. This sulfurization produces an extremely low pH, yellow jarosite $[KFe_3(SO_4)_2(OH)_6]$ mottles, sulfate ions, and cations such as Ca^{+2} , Mg^{+2} , K^+ , and Al^{+3} . Certain elements such as Al and Mn become toxic to plants and may contribute to vegetation failures on minesoils. Concentrations of Fe and Cu, may also be toxic to plants, and they are most likely to occur where plant-toxic Al and Mn are present.

AMD has an ability to dissolve metals due to its low pH, as low as 3,1. There is considerable variation, however, in AMD characteristics from coal and other sources. These dissolved constituents (such as iron, aluminium, and manganese) at various concentrations are typically the result of the chemical and biological weathering of sulfide minerals. The AMD in Tanjung Enim, Indonesia has a pH of ≈ 3 and Fe concentrations ranging from 500 to 1500 mg L⁻¹. One of the concerns of coal mining has been the potential of metal leaching into the cover waters and therefore, increasing the metal concentrations in the water to above the acceptable limits.

The objective of this study was to document the relative leaching of selected ion metals that occur when unoxidized overburden containing acid-forming and non-acid forming materials are used as topsoil substitutes.

Material and Method

The relative leaching of the cations was studied in 3 cm (i.d) x 20 cm (length) glass column packed with 100 g of overburden previously sieved through a 4-mm screen. The OB were sampled at two different acid-producing materials: high sulphide, pyritic OB (PAF), and low sulphide (NAF). The OB was crushed to pass through a 13-mm sieve, characterized, and packed into the column. To prevent some breakthrough of soil particles, a sieving paper was placed in the bottom of the column. The columns were leached with 60 mL of AMD under a saturated flow, collecting 25-mL each fractions in which the concentrations of Ca, Fe, Al, Pb, Al were measured. At the end of the leaching, the OB were analysed using soil analyses methods.

For laboratory analyses, all samples were air dried, then sieved through a 2-mm sieve. Particle size distribution of the < 2-mm fraction was analysed by the pipette method (Day, 1965). Soil reaction was determined in 1:1 soil/water extract and referenced to a standard 0,01 M KCl solution (Rhoades, 1982). Ion metals were analysed by atomic absorption spectrophotometry (Thomas, 1982). To determine the total content of the metals in the OB, 1 g of finely sample was dissolved in 7,5 mL of the HCl and 2,5 mL HNO₃.

The XRD analyses were conducted on powder mounts of samples using a diffractometer (PW 1840, Phillips) with Co K α radiation. Rock petrography of the OB was quantified by a point-count method.

Results and Discussion

The initial characteristics of the overburden are summarized in Table 1. Both overburdens have similar clay contents and no carbonate. S2 is a potential acid forming material, with NAG value at pH 7 was 105,02 kg H₂SO₄/tonnes overburden, while S4 is a non acid forming material with NAG value at pH 7 was 0,94 kg H₂SO₄/tonnes overburden. An overburden with an NAPP value < 10 in theory is a non acid forming material, has sufficient quantities of acid-neutralizing material present to neutralize potential acidity as it is released via sulfide oxidation.

Table 1 Characteristics of initial overburden

Property	Value	
	S2	S4
Clay (%)	30	35
pH	2,20	4,48
Total Sulphur (%)	2,60	0,08
Carbonate	0	0
Organic Carbon	10,98	1,39
Maximum potential of acidity (kg H ₂ SO ₄ /tonnes overburden)	79,56	3,25
Acid neutralizing capacity (kg H ₂ SO ₄ /tonnes overburden)	-	-
Nett acid producing potential (NAPP) (kg CaCO ₃ /tonnes overburden)	79,56	3,25
Nett acid generating (NAG) pH	2,00	6,41
Nett acid generating (NAG) pH 4,5 (kg H ₂ SO ₄ /tonnes overburden)	78,23	-
Nett acid generating (NAG) pH 7 (kg H ₂ SO ₄ /tonnes overburden)	105,02	0,94
Category	potential acid forming material (PAF)	Non acid forming material (NAF)

Mineralogical Analysis

The interpretations from the XRD patterns are qualitative. Sharp peaks characteristics of quartz (Q) were present in all samples. Diffraction pattern of samples showed diffraction band at 7,16 Å and 3,57 Å which are consisted with kaolinite; and at 1,63 Å, 2,71 Å or 2,34 Å which is indicative of pyrite. Sand fraction analysis showed S2 contained quartz, orthoclase, sanidin, and S4 quartz, orthoclase, sanidin, albite, iron- concretion and limonite.

Leachate Analysis

Figure 1 shows a different curves of pH with different AMD pH. In general, the pH of successive leachate samples gradually increased to a relatively constant pH of 2,0 for S2 and 8,0 for S4 during the final of the experiment. From these data, it is apparent that the overburden's inherent acid potential was capable of neutralizing the H_2SO_4 released by pyrite oxidation during this time. But, the pH of leachate samples gradually decreased to a relatively constant pH of 1,5 for S2 and 2,0 for S4.

Figure 1 Leachate pH in S2 and S4 with different AMD applications

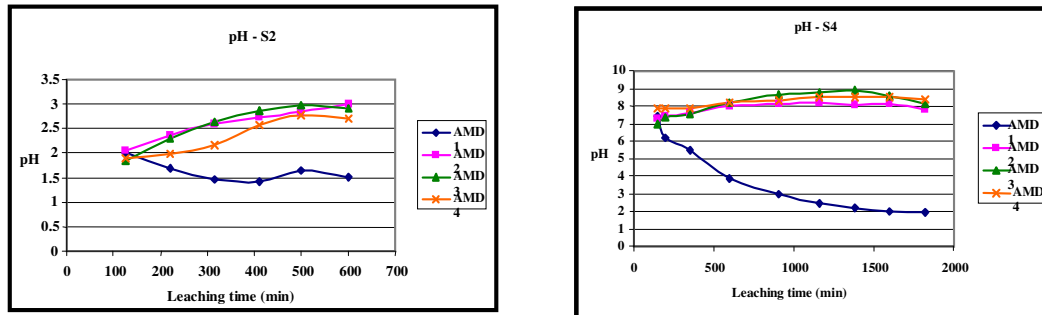


Figure 2 shows the leaching curves of the selected metals. Data are presented in the plots as metals cumulative amounts in the leachate (amount, mg) versus leaching time with different AMD pH. The amounts of metal leached are in order $Fe > Ca > Al > Pb$. This kind of behaviour is in agreement with results showing that Pb is the least mobile metal. Concentration differences in the effluent and influent leachate indicated that Al and Pb were retained (the levels of these heavy metals in effluent were lower than that of the influent).

The increase in Fe^{3+} in S4 indicates that the OB could be undergoing oxidation under the flow through test. The artificial AMD did not contain Fe, the Fe was probably mobilized from iron- concretion and limonite dissolution. As Fe^{3+} is a strong oxidant, it may leached due to the AMD pH which very low and not enough anion present that could bound Fe as a precipitant. Under pH 3, iron is in mobile condition. Precipitation noted at the S2 may be related to the precipitation of ferric oxyhydroxides, which resulted in an elevated in Fe concentrations noted in the leachate.

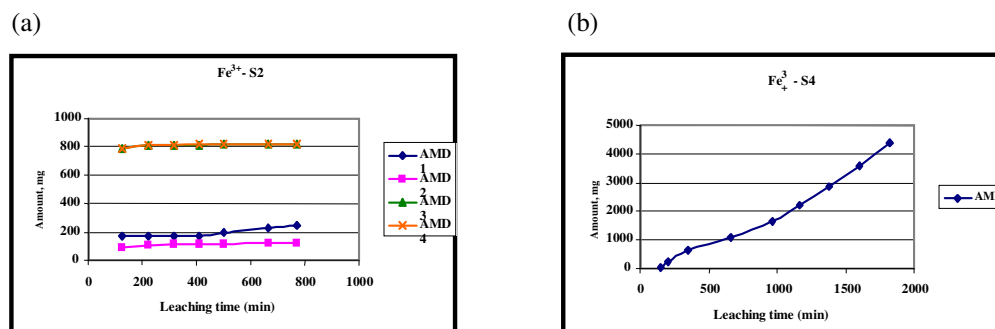
The concentration of Ca in the both leachate has similar pattern. It increased with the application of AMD pH 1 and 2, and relatively constant with AMD pH > 2 throughout the study; however, there was a significant linear increase in S2 (Fig. 2c). Since there was no carbonate in both overburden, the source of the Ca was probably from the dissolution of labradorite, hornblende or other trace minerals.

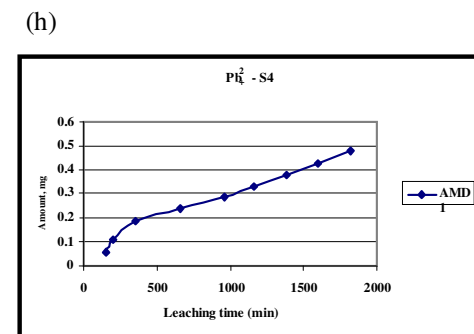
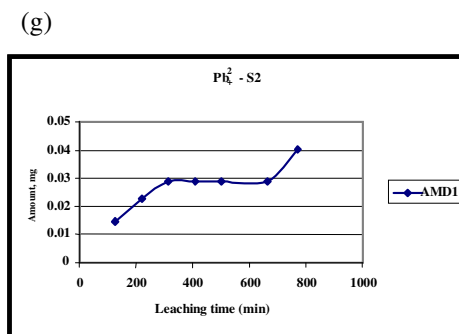
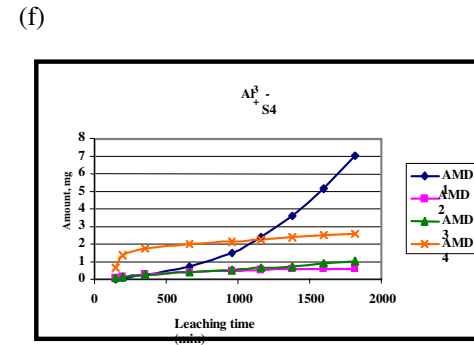
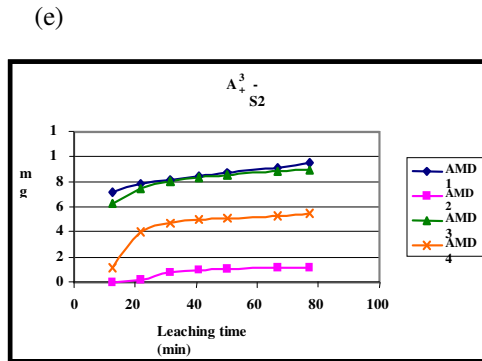
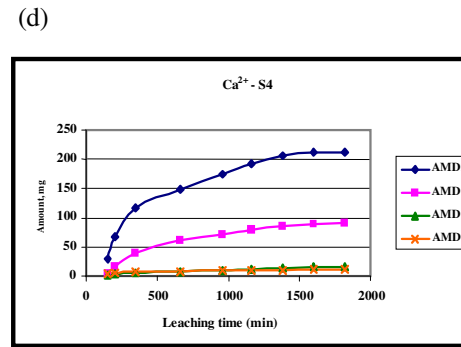
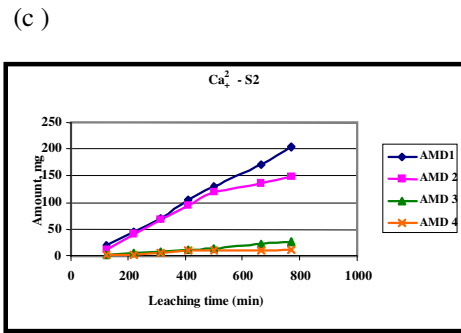
The concentration of Al in the both leachate has similar pattern except for leachate from AMD pH 1. It was increased constantly. The Al was probably mobilized from silicate dissolution.

Other metal concentrations did not exhibit significant increases in the leachate.

Pb only present in the leachate collected from both OB leached by AMD pH 1. Pb is strongly retained by OB's particle and has very low dissolution capacity.

Figure 2 Analysis of leachate from S2 and S4 which were leached with different AMD pH: (a) and (b) amounts of Fe^{+3} , (c) and (d) Ca^{+2} , (e) and (f) Al^{+3} , (g) and (h) Pb^{+2}





From the four metal studied, Fe and Ca need more attention. Cation leaching rates were between $1,15$ to $1,96 \times 10^1 \text{ mg L}^{-1} \text{ minute}^{-1}$ (Table 2). Iron easily dissolve to water body and could polluted the water by the iron hydroxide precipitation. While Ca could restrict the yields of most plants due to the formation of gypsic or petrogypsic horizon. A restrictive layer such as this would decrease vertical movement of water and oxygen, reduce vegetative growth, and increase runoff and erosion.

Table 2 Leaching rate of selected metals from overburden compare to those in soil

Metals	Leaching rate, $\partial[L]/\partial t$	Hoosbeek dan Bryant
Fe	$1,96 \times 10^1 [\text{H}^+]^{0.23}$	$2,23 \times 10^{-3} [\text{H}^+]^{1.63}$
Ca	$1,15 \times 10^1 [\text{H}^+]^{0.49}$	$8,58 \times 10^{-3} [\text{H}^+]^{1.09}$
Al	$1,18 [\text{H}^+]^{0.02}$	$7,62 \times 10^{-4} [\text{H}^+]^{0.80}$
Pb	$8,49 \times 10^{-3} [\text{H}^+]^{0.2}$	-

Overburden Sample Analysis

Table 3 shows the metals remained in the overburden. The metals leached in $S2 > S4$. A series of chemical and physicochemical processes are involved in the vertical leaching or mass flow of metals

in the soil (Alloway, 1995). In turn, these depend on the chemical characterised of each metal and on the soil parameters such as pH, carbonates content, free iron and Al oxide contents, and the nature and content of the clay and organic matter fractions (McBride, 1994). Regarding to overburden, the analysis revealed that both OB did not contain carbonate and had similar value of clay. It is therefore leaching capacity of selected metals studied here depend on sulphide content and the reaction value of AMD.

Table 3 Selected total metals of overburden

Samples	Fe	Ca	Al	Pb
	ppm			
S2	10189	3376	65297	2,68
S2-AMD1	8153	1088	45901	2,57
S2-AMD2	11988	1688	56666	2,99
S2-AMD3	13555	1475	65253	3,01
S2-AMD4	7874	767	45943	4,05
S4	31500	2200	21000	12,0
S4-AMD1	40300	1400	29300	13,5
S4-AMD2	27471	1626	25828	2,09
S4-AMD3	34192	2233	30811	2,73
S4-AMD4	29964	2048	25500	2,75

Conclusions

The amounts of metal leached are in order $Fe^{+3} > Ca^{+2} > Al^{+3} > Pb^{+2}$. The most abundant metal released from the overburden is iron follow by calcium. Investigations revealed a greater leaching intensity evidenced by: (i) higher sulfur content and (ii) lower AMD pH. Selected cations Fe^{+3} and Pb^{+2} undetectable with increasing the AMD pH (from 1 to 2).

References

- Alloway BJ (1995) Soil processes and the behaviour of heavy metals. In: Alloway BJ (Ed). Heavy Metals in Soils. Glasgow, Chapman and Hall, p 11-35.
- Doolittle JL, Hossner LR, LP Wilding (1993) Simulated aerobic pedogenesis in pyrite overburden with a positive acid-base account. Soil Sci. Soc. Am. J 57:1330-1336.
- McBride MB (1994) Environmental chemistry of soils. NY, Oxford University Press.
- Schafer WM, Nielsen GA, and Nettleton WD (1980) Minesoil genesis and morphology in a spoil chronosequence in Montana. Soil Sci.Soc.Am.J. 44:802-807.
- Sencindiver JC, Ammons JT (2000) Minesoil genesis and classification. In: Barnhisel RI et.al (Ed) Reclamation of drastically land. Agron. Monogr. 41. ASA, CSSA and SSSA, Madison, WI. p: 595-613.
- Suryaningtyas DT (2006) Study of metal ion leaching on overburden in open mining as a land reclamation alternative method. Ph.D.diss. Bandung Institute of Technology, Bandung, Indonesia.
- Thomas KA, Sencindiver JC, Skousen JG, Gorman JM (2000) Soil development on a mountaintop removal mine in southern West Virginia. In: Daniels WL, Richardson SG (Eds) 2000 Proceedings Annual Meeting of the American Society for Surface Mining and Reclamation, p 546-556.