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<https://hdl.handle.net/2324/4355467>

出版情報 : Journal of Geoscience and Environment Protection. 8 (5), pp.56-64, 2020-05-12.
Scientific Research Publishing

バージョン :

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How to cite this paper: Win, T. S., Dwiki, S., Hamanaka, A., Sasaoka, T., Shimada, H., Mastumoto, S., & Kusuma, G. J. (2020). Application of Fly Ash and Organic Material as Dry Cover System in Prevention of Acid Mine Drainage Generation. *Journal of Geoscience and Environment Protection*, 8, 56-64.

<https://doi.org/10.4236/gep.2020.85004>

Received: April 16, 2020

Accepted: May 9, 2020

Published: May 12, 2020

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Abstract

The common practice in AMD prevention is a dry cover technique. In this technique, rock that is potential in producing acidity (PAF) will be placed below non-acid producing rock (NAF). Depends on NAF availability in the mine site situation, organic covers can be used to prevent diffusion of oxygen into reactive sulphide wastes and subsequently to eliminate sulphide compounds oxidation and generation of acidic waters. The utilization of additional material cover layer is proposed, by using fly ash and organic material combination. To investigate the possibility of using these materials, a column leaching test in the laboratory scale was conducted with several scenarios of simulation. By comparing between column with different thickness of fly ash and organic material, the leachate water behavior is observed in the experiment, including the measurement of water quality (pH and EC), major cations-anions. The result suggests the possible thickness of fly ash (FA) and organic material (OM) as cover layer material, especially in the case of mine with domination of PAF rock material.

Keywords

AMD, Fly Ash, Organic Material, Dry Cover, Coal Mine, Column Leaching

1. Introduction

Coal mining is one of the major parts of mining sector that provide worldwide energy. Many countries in the world depend on thermal coal for generating the

electricity that will be used for industrial scale until household purposes. As the coal mining operations increase, negative impact that happens as the effect of coal extraction also arise. Among the impacts, AMD is the prominent and serious issue that causes long-term impairment to waterways and biodiversity as the effluents contain toxic substances that have serious impact to human health and ecological (Akciil & Koldas, 2006). Once it occurred, AMD might last for years or even decades without human intervention and strictly depend on the availability of its sources. Thus, AMD should be carefully monitored, controlled and well-treated.

AMD prevention consists of several methods. In general, the purpose of prevention is the minimization of AMD factors such as oxygen supply, water infiltration and leaching, sulfide mineral availability and bacteria (related to biogeochemical process). Moreover, maximizing the availability of acid neutralizing minerals or increasing the infiltrated water pH could also be regarded as an option. So far, the best practice methods in mining site are special handling, segregation, encapsulation, dry and water cover (Lottermoser, 2010). Dry cover is considered as the most effective method to minimize penetration of air and water (O'kane & Wels, 2003; Wilson et al., 2003). It is also an inexpensive method and moderately simple to be constructed, as the cover layer usually depends on the material availability on the mining site. The common practice is segregating non-acid forming rock material and potentially acid forming material, then placed the potentially acid forming below the non-acid forming. Subsequently, the material layer with acid forming potential is located underneath the non-acid forming rock layer. Non-acid-forming layer thus cut off the oxygen supply and water infiltration. The numerous mining sites already applied this method in their field while several researches were conducted to study about the efficiency and long-term impact of dry cover to AMD (Gautama et al., 2013; Kusuma et al., 2012).

The current research proposed the application of fly ash and organic material as dry cover system to mitigate acid mine drainage generation especially to improve water drainage in mine site. The impact of fly ash and organic material as cover material for material layering underneath, especially the thickness changes is also evaluated.

2. Sampling and Analytical Methods

2.1. Sampling

Rock samples were obtained from active open-cut coal mining in Indonesia located in Sumatra. The rock was sampled by grab sampling, after digging the rock material for around 15 cm in the depth. About 2 kg of samples for each rock in the total were collected, in the bulk size. The collected samples were analyzed by static test to know the capacity in producing acid. In this study, the common static test methods such as acid base accounting (ABA) (Sobek, 1978) and net acid generation (NAG) test (Miller et al., 1997) were used to characterize the

rock geochemistry in order to predict AMD potential (AMIRA, 2002). The ABA method consists of paste pH and EC, total sulfur (TS) test and acid neutralizing capacity (ANC) test.

Fly ash was collected at coal-steam power plant nearby coal mining. Organic material was obtained from the palm oil processing company that has a plantation area adjacent to the coal mining. This organic material is a waste from the empty fruit bunches of oil palm surrounding mine site.

Major element and mineralogical analysis were carried out by using XRF and XRD analysis, respectively. Rigaku 3100 X-ray fluorescence spectrometer was used for XRF analysis while XRD analysis was performed using Rigaku RINT 2000 X-ray diffractometer.

2.2. Paste pH and EC Test

The pH and EC are measured to the paste of the sample with a ratio of rock and distilled water is 1:2 (AMIRA, 2002). Rock sample is pulverized beforehand in order to obtain a fine mixture of paste. In that way, the sulfide mineral is well oxidized after letting the paste reacts overnight (12 to 16 hours). The determination of pH and EC is directly measured to the paste mixture of distilled water and powder sample, which indicate the inherent acidity and salinity of the rock within the initial exposition to the air.

2.3. Acid Base Accounting (ABA) Method

The total sulfur is measured with XRF. Maximum potential acidity (MPA) then can be calculated from TS with assumption all of sulfur measured in the form of pyritic sulfur. The MPA is calculated using the formula: $\text{MPA (kg H}_2\text{SO}_4/\text{ton)} = 30.625 \times \text{Total Sulfur (\%)}$.

Acid neutralizing capacity (ANC) test is determined with known amount of standardized hydrochloric acid (HCl) addition to the weighted powder sample which back-titrating afterwards with NaOH to calculate amount of acid consumption. This process aims to obtain quantification of the inherent acid buffering of sample after reacting the sample with strong acid. The acid consumption is reacted directly, with the aid from 1 to 2 hours heating to accelerate the reaction. Based on the MPA and ANC result, NAPP is calculated by acid-base balance calculation method from the formula: $\text{NAPP (kg H}_2\text{SO}_4/\text{ton)} = \text{MPA} - \text{ANC}$.

2.4. Net Acid Generation (NAG) Test

The NAG measurement was carried out by adding hydrogen peroxide to the weighted pulverized sample. As a strong oxidizer, hydrogen peroxide forces the mineral to react, after allowing the reaction to happen for at least overnight then follow by heating to accelerate it. In the reaction, both acid generation and consumption simultaneously take place, therefore the measurement result of NAG pH indicates the net acid and/or base left in the rock sample after the acid producing and consuming occurred.

2.5. Column Leaching Test

The leaching simulation followed a method of Free Draining Column Leach test from AMIRA, with modification. A column that was used in this simulation has diameter 50 mm and total height 150 mm, while column to the control column per layer had diameter 50 mm and total height 50 mm. Layering scenario was selected due to the consideration of mining method that is used in mine site. Moreover, layering scenario has been proven as an effective method for AMD prevention based on the previous study (Kusuma et al., 2012).

The simulation consists of column with three different thickness ratio of fly ash mixed with NAF rock and organic material cover layer shown in **Figure 1**. This was carried out to investigate the effect of cover in the AMD generation. In columns 1 and 2 cover layers, there are two scenarios comparing ratios 1:0.5 of FA and OM, and 0.5:1 of FA and OM. In columns 3 and 4 cover layers, there are two scenarios comparing ratios 2:1 of FA and OM, and 1:2 of FA and OM. In columns 5 and 6 cover layers, there are two scenarios comparing ratios 3:1.5 of FA and OM, and 1.5:3 of FA and OM. The purpose is to compare the effectiveness of cover in the case of a different fly ash and organic material amount. The NAF material was placed together with fly ash by blending uniformly with ratio 1:0.5 of NAF and fly ash in column 1, ratio 0.5:1 of NAF and fly ash in column 2, ratio 2:1 of NAF and fly ash in column 3, ratio 1:2 of NAF and fly ash in column 4, ratio 3:1.5 of NAF and fly ash in column 5 and ratio 1.5:3 of NAF and fly ash in column 6. In the control column PAF, NAF and fly ash and organic material were investigated.

Leaching test was conducted for 14 days in the total, with phases of wetting and drying in order to resemble the mining field condition. The drying phase

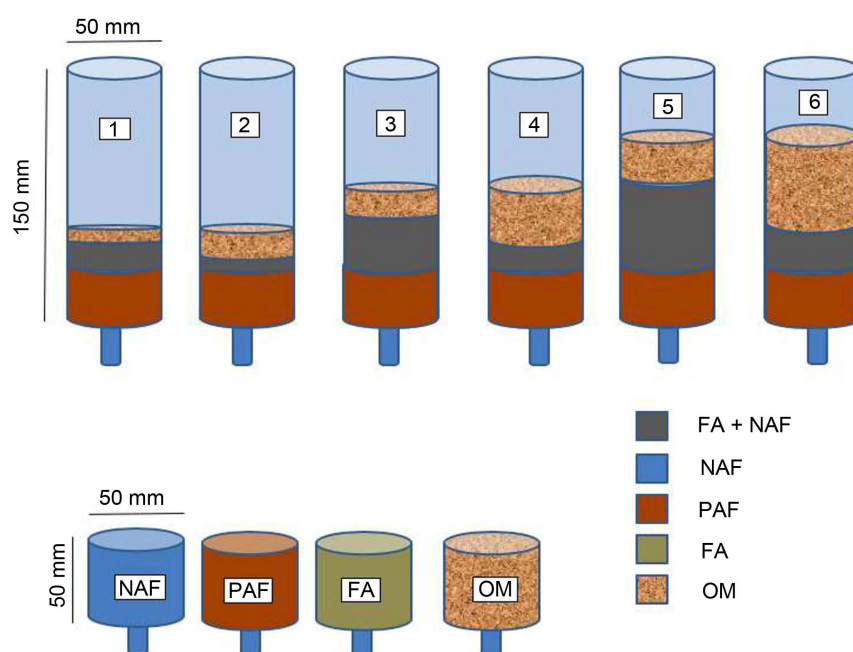


Figure 1. Leaching column configuration.

was a daily cycle, with 12 hours heating by the lamp (measured temperature in the column, $T = 35^{\circ}\text{C} - 40^{\circ}\text{C}$) and 12 hours natural drying. Spraying the deionized water was conducted for wetting phase while the volume of leachate water is 150 mL/cycle. After the leachate water came out, it directly measured for pH and EC (electrical conductivity). Then, leachate water was filtered with $0.45\ \mu\text{m}$ filter and acidified. Major cation-anion measurement then conducted by using Dionex ICS-90 ion chromatography.

3. Results and Discussion

Table 1 shows the results of static test and **Figure 2** shows the format of the classification plot that is typically used for presentation of geochemical data. Marked on this plot are the quadrants representing the classification of NAF, PAF and Uncertain (UC). Based on the geochemical classification, 6 samples were categorized as a PAF sample while 2 samples were NAF sample. Rock sample that were categorized as NAF material and shows better result from static test was used further experiment. The same procedure was also used to choose the PAF material. Based on the static test results, we selected the sample for column leaching test, P1 for PAF, N1 for NAF, and FA for fly ash.

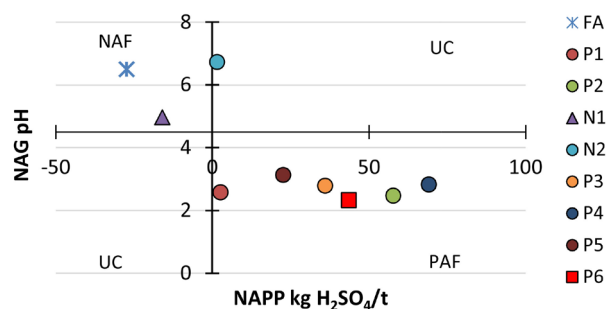


Figure 2. Geochemical classification plot of the samples.

Table 1. Static test result of rock samples.

Sample	ANC	MPA	NAPP	NAG pH	Paste pH	Paste EC
	kg H ₂ SO ₄ /ton					μS/m
P1	18.40	21.00	2.60	2.58	7.67	2.02
P2	0.00	57.72	57.72	2.47	6.89	1.86
P3	0.00	35.98	35.98	2.79	4.41	3.10
P4	0.00	69.07	69.07	2.83	4.89	2.10
P5	0.00	22.57	22.57	3.13	6.57	1.96
P6	18.40	43.56	43.56	2.33	2.36	5.30
N1	20.31	4.33	−15.97	4.97	6.53	0.83
N2	0.00	1.49	1.49	6.73	6.48	1.02
FA	83.10	55.71	−27.39	6.50	10.4	4.40

From the XRD analysis, the PAF consists of quartz (SiO_2), illite ($\text{KAl}_2\text{Si}_3\text{AlO}_{10}(\text{OH})_2$), kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$), siderite (FeCO_3), pyrite (FeS_2), and arsenopyrite (AsFeS_3). Meanwhile, the NAF consists of quartz (SiO_2), chlorite ($(\text{Mg, Fe})_5(\text{Al, Si})_5\text{O}_{10}(\text{OH})_8$), kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$), siderite (FeCO_3), illite ($\text{KAl}_2\text{Si}_3\text{AlO}_{10}(\text{OH})_2$) and jarosite ($\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$). The fly ash has mineralogy as follows: quartz (SiO_2), illite-montmorillonite ($\text{KAl}_4(\text{Si, Al})_8\text{O}_{10}(\text{OH})_4 \cdot 4\text{H}_2\text{O}$), chlorite ($(\text{Mg, Fe})_5(\text{Al, Si})_5\text{O}_{10}(\text{OH})_8$), dolomite ($\text{CaMg}(\text{CO}_3)_2$), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), siderite (FeCO_3), aluminum oxide (Al_2O_3), andradite ($\text{Ca}_3\text{Fe}_2^{+3}(\text{SiO}_4)_3$) and magnetite ($\text{Fe}^{2+}\text{Fe}^{3+}\text{O}_4$).

Result of Column Leaching Test

The pH and EC measurement result of 10 columns was presented in the graph of **Figure 3**. Column PAF resulted in the acidic leachate water, with pH value ranged from 2.3 - 4 and the average value during the pH measurement was 2.88. This outcome was expected, since from the mineralogy analysis the PAF material has pyrite and arsenopyrite existence detected from XRD. Moreover, static test has analyzed the acid producing capacity of PAF material which showed high potential in generating AMD. Column 1 also produced leachate water that in the similar value with PAF first 4 cycle, even though in column 1 and column 2 contained with ratio 1:0.5 of fly ash and organic material cover. Column 1 pH value ranged from 2.6 - 5.7 with the average pH value was 4.23. Column 2 pH value ranged from 2.9 - 5.9 with the average pH value was 4.4. On the contrary, the column 3 with ratio 2:1 of fly ash and organic material cover and column 4 with ratio 1:2 of fly ash and organic material cover produced near neutral to alkaline leachate water. Column 3 pH ranged from 4.8 - 7.53 with the average pH value was 7.12 while column 4 pH ranged from 3.7 - 7.7 with the average pH value was 6.03. This result was in concordance with the result of FA and organic material control column that has a high pH value of leachate water, ranged from 8.48 - 10.89 with the average 9.59. Unexpectedly, the column 5 with ratio 3:1.5 of fly ash and organic material cover and column 6 with ratio 1.5:3 of fly ash and organic material cover produced acidic leachate water. Column 5 pH ranged from 3.4 - 6.0 with the average pH value was 4.57 while column 6 pH ranged from 3.8 - 6.2 with the average pH value was 5.0. This may be because the volume of leachate water was small, meaning that the permeability was too small to conduct the column leaching test for this study. The cover of fly ash and organic

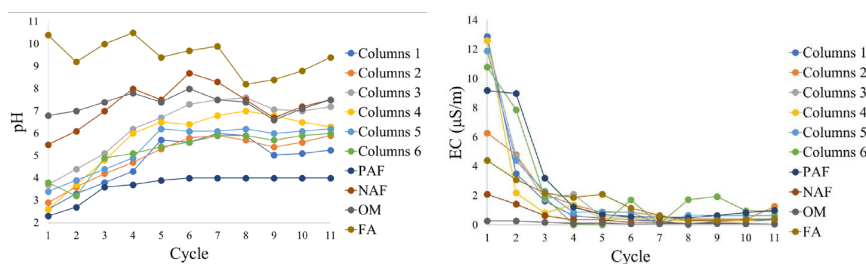


Figure 3. pH and EC leachate water measurement result.

material cover improves the AMD by consuming the acidity and mitigating oxygen diffusion. Therefore, even though PAF could generate acidic water, the flowing water from cover material and the effect of consuming oxygen will buffer the pH and improve the water quality. Based on column leaching test result, fly ash amount is better to use thickness with minimum 0.5 times of PAF. Additionally, the design of Column FA:OM (2:1) shows more efficient results.

EC is a measure of the ability to pass current in aqueous solution from the dissolved material. Based on the measurement result, PAF control column had the highest EC on the average, as expected from the low pH measurement result. By comparing the EC from the Column 1 and Column 2, the significant value difference can be seen. Therefore, it was assumed that the fly ash had contributed in decreasing the number of dissolved ions of the leachate water. In the case of higher ratio of cover material, column 5 and column 6 showed lower EC value that indicates even less ions dissolved in the column than column 3 and column 4. This result also supports the cover of fly ash and organic material contributes to mitigate AMD generation. Additionally, the dissolution of heavy metals from fly ash seems insignificant in this experiment due to the quite lower EC.

Based on the result of major cations-anions measurement, the major anion was sulfate while the major cations were calcium (see **Figure 4**). From the result, the largest sulfate concentration was found from PAF column. In this column, sulfate anion was likely dissolved from the weathering of sulfide mineral, pyrite and arsenopyrite. Based the sulfate measurement, it can be said that PAF column has the most acidity generated within the column. This was also supported by the lowest pH value among the columns as mentioned earlier. Interestingly, Column 6 had quite a high sulfate concentration in the beginning. However, as the time elapsed, the sulfate kept decreasing and finally had the similar sulfate concentration like the other column.

For the dissolution of cation, a significant amount of calcium can be seen from the measurement result of the every column with cover and FA, which means a fly ash contributed for the increasing Ca in the leachate water. Ca content of the column with cover were originated from fly ash that contain high calcium, in the form of lime (CaO) and dolomite, based on the XRD analysis. Those minerals dissolve easily after reacting with water, that also supported by the pH measurement that significant increased. The dissolution of those minerals

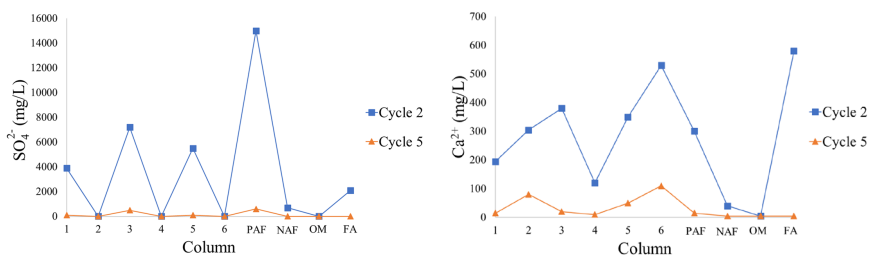


Figure 4. Major cation-anion measurement result of each column.

produces the hydroxide ion which will consume acidity in the water and increase the water pH.

4. Conclusion

Column leaching experiment for studying the possibility of using fly ash and organic material as cover layer material was carried out in this study. As a result, the utilization of fly ash and organic material as cover layer is effective to prevent AMD generation, by increasing the leachate water pH, consuming the oxygen in the upper layer and reducing the dissolved metal concentration. Based on the measurement of major cations-anions, the dissolution of sulfate keeps decreasing and finally shows the quite lower concentration for the column with covered scenario and the dissolution of lime and dolomite from fly ash attributes to neutralize the acidic water. Utilization of fly ash and organic material as cover layer is effective to prevent AMD generation, by increasing the leachate water pH, consuming the oxygen in the upper layer and reducing the dissolved metal concentration. More importantly, changing ratio of cover material shows particularly difference of pH and EC value. Based on column leaching test result, fly ash amount is better to use thickness with minimum 0.5 times of PAF. Additionally, the design of Column FA:OM (2:1) shows more efficient results. Fly ash and organic material combination as cover layer thus far shows no negative impacts may happen due to its utilization. Therefore, it is important to conduct this experiment in the field scale to know the behavior of leachate water in the field situation.

Acknowledgements

The authors would like to gratefully acknowledge KIZUNA Program, Japan International Cooperation Agency (JICA) for financial support. We acknowledge kind and strong supports from Director General and Staff Members of Department of Mines, Ministry of Natural Resources and Environmental Conservation, Myanmar for this study. The authors would like to express sincere thanks to Associate Professor Dr. Myo Min Tun, Kyaukse University, Myanmar for support and encouragement throughout my study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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