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The Mine Drainage Quality Prediction of Surface Coal Mine Rock Samples with Humidity Column Test

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Abstract. A kinetic test, namely Humidity Column Test (HCT) was conducted in the laboratory to predict the mine drainage quality of two samples from a coal mine in Kalimantan, Indonesia. Furthermore, the study calculated the weathering rate of these samples per cycle and identified the parameters controlling the weathering process. The samples came from fresh rock of the active pit (PE) and disposal area (Q10). A static test was conducted to these samples and showed the classification results of the samples. HCT used uniform particle size distribution and aimed to interpret the kinetics of the acid generation. The results of 7 cycles (56 days) experiments are presented here. Based on the kinetic test, PE was classified as PAF high capacity and Q10 was classified as PAF intermediate capacity. The intensity of weathering rate was indicated by TDS (Total Dissolved Soil). It was in line with the pH paste results: the smaller paste pH, the faster the weathering rate. PE tended to weather faster than Q10.

INTRODUCTION

One of the most critical environmental problems in surface coal mines in Indonesia is acid mine drainage (AMD) [1]. The authorized agencies in mining operations and the environment have set up some actions to supervise this issue. One of the practical solutions is the geochemical characterization of overburden [2]. Its goal is to classify the overburden into potentially acid-forming (PAF), uncertain (UC), and non-acid-forming (NAF). Furthermore, the result of the classification can be the guideline for mining practitioners to design sustainable disposal area, explicitly preventing the AMD generation [1]. Another common practice done by small to medium scale mines is controlling water discharge quality from mine operations (pH) before releasing to surface water body [4].

The geochemical characterization can be divided into the static and kinetic test [5]. The conventional static test includes acid-base accounting and net acid generation. The shortage of static tests is lack of accuracy in classifying samples and do not provide the rate of sulfide minerals oxidation and neutralization potential of the rock samples [1] – [3]. Whereas, these two parameters are essential to forecast the water quality for long-term purposes [5]. The kinetic tests are performed to overcome the shortage of static tests and to ensure the result of the static tests [5] – [7].

The research will go through one of the most common kinetic test, humidity column test, on two rock samples classified as PAF and UC. The experiments were taken place in the laboratory. The main goal of this research is to understand the long term behavior of the rock samples by analyzing the leachate quality, the weathering rate, and the pertaining parameters, and to confirm the result of the static tests.

MATERIALS AND METHODS

Materials

Two rock samples were collected from an active pit (PE) and a disposal area (Q10) in Kalimantan, Indonesia. The samples had been tested for static tests, including paste pH, total Sulphur, and neutralization capacity to classify the samples into PAF, UC, and NAF category in Table 1 [6] – [8]. Based on the classification in the ARD Handbook, PE is categorized as PAF and Q10 is categorized as UC. Considering the ratio of ANC/MPA of Q10, which equals to 0, this sample tends to be PAF [9].

TABLE 1. The Static Tests Result of The Samples

No	Code	Paste pH	ANC	NAG pH	NAG		Tot. Sulfur (%)	MPA	NAPP	ANC/ MPA	Class.
					pH 4.5	pH 7					
1	PE	2.65	0.00	2.47	25.51	35.86	1.93	59.06	59.06	0.00	PAF
2	Q10	3.02	0.00	4.97	-	8.87	1.20	36.72	36.72	0.00	UC

Note: ANC = Acid Neutralizing Capacity (kg H_2SO_4/ton); NAG = Net Acid Generating (kg H_2SO_4/ton); MPA = Maximum Potential Acidity, NAPP = Net Acid Producing Potential, PAF = Potential Acid Forming, UC = Uncertain.

Methods

Kinetic tests were performed using a free-draining humidity column test on a 20 cm height and 10 cm diameter acrylic column (Fig. 1a). Each sample (4-5 kg) undergone a crushing process up to 2.5 cm in size. Sieving analysis was performed for six sieve meshes; top sample (US #3, US #4, US #8) and bottom sample (US #14, US #20, and US #28). As much 250-300 grams of known size particle distribution sample was put into four acrylic columns. Laboratory temperature was maintained between 28-35 ºC to simulate local weather condition using 60-light bulb.

The weathering simulation consisted of 3 cycles; dry cycle, wet cycle, and flushing cycle. The simulation started with initial flushing of 0.45 L distilled water. Duration of dry, wet, and flushing cycle is three days, four days, and one day, respectively. After initial flashing, the four samples underwent the dry cycle for three days. Gases were blended to a ratio of 90% air to 10% CO_2 using flow meter (Fig. 1c). During the wet cycle, blended gas was introduced into the distilled water in the Erlenmeyer flask through bubbler media. Entering day-8, the samples underwent a flushing cycle using distilled water. During this cycle, the blended gas flow was temporarily stopped for a day, and each sample column was flushed to 0.45 L distilled water. The leachate was collected for analysis. The simulation was conducted for seven cycles (56 days).
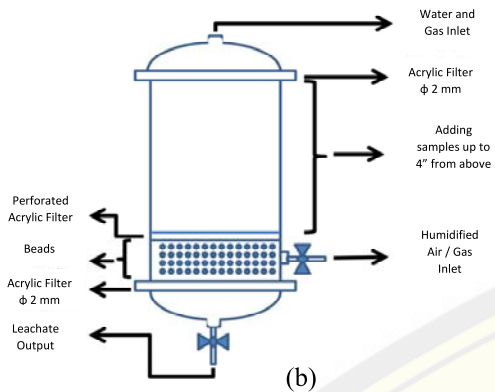

(a)

(b)

(c)
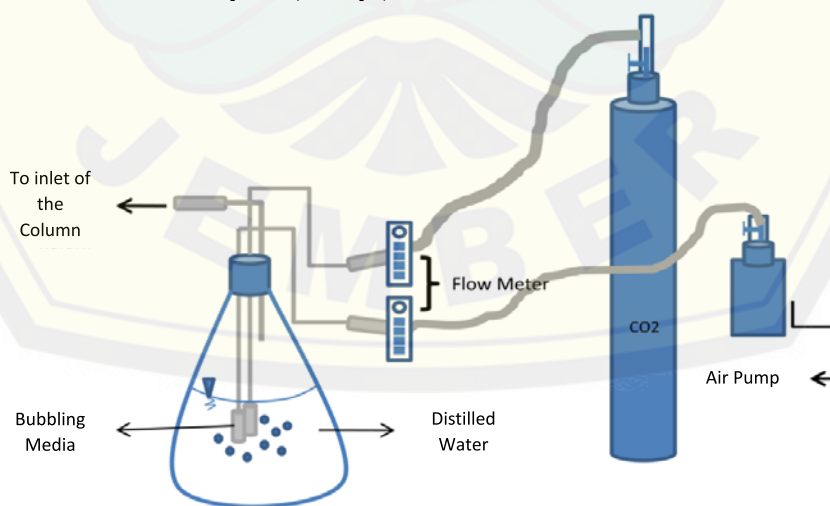
FIGURE 1. The Apparatus of The Simulation: Illustration of The Gas Mixture Apparatus (a); Illustration of the Column Apparatus (b); Actual set-up of The Column Test (c)

RESULTS AND DISCUSSION

Physical and Mineralogy Comparison

The wet dan dry cycles play an essential role in the acid generation of the samples. Both cycles will influence the physical and chemical process that exist in the column. Physically, these cycles lead to the physical disintegration of the sample. Consequently, the particle size of the samples will deteriorate. This circumstance will accelerate the chemical process (the oxidation rate of sulfide and the neutralizing potential) due to the increase of the reactive surface area in the sample [9] – [10]. Furthermore, the finer-grained sample due to physical deterioration will have a higher water holding capacity because of the low permeability on sample pores. The presence of water in the sample pores will affect the oxygen diffusion, slaking, and chemical process inside the rock sample [11]. In this research, sample reconstruction was performed by particle size distribution analysis. This procedure was performed because the samples from the field will lose the particle size distribution during the field sampling and crushing procedure. The size distribution in Table 2 will create uniformity on the weathering process of the samples and leachate collection. After 56-days of simulation, physically the grain in each column weathered into a smaller size. The physical comparisons of the samples before and after the simulation are shown in Fig. 2. The bottom samples (PE_B and $Q10_B$) samples experienced more weathering process than the top samples.

The X-Ray Diffraction (XRD) test was performed twice; before and after simulation. The aim was to check the reactivity of the mineral within the samples, particularly sulfide minerals. Furthermore, the test was also to ensure that at the end of the simulation, whether all sulfide minerals were weathered and leached. The XRD result of the rock samples before and after the simulation is shown in Table 2. The result gives information that after 56-days of simulation, the sulfate mineral (Coquimbite) and carbonate-silica minerals still exist in all columns. The presence of these minerals showed undergoing oxidation and neutralizing activity.

TABLE 2. The Result of Size Distribution Analysis

Mesh Size		PE (g)		Q10 (g)	
Top	-3#+4#	64.34		69.88	
Top	-4#+6#	107.17		88.86	
Top	-6#+8#	87.64		104.55	
Bottom	-8#+14#		151.76		145.05
Bottom	-14#+20#		49.77		72.45
Bottom	-20#+28#		60.88		47.51
Total		259.15	262.41	263.29	265.01

TABLE 3. The XRD Result of the Rock Samples

No	Mineral	Formula	PE	PE$_T$	PE$_B$	Q10	Q10$_T$	Q10$_B$
1	Quartz low	SiO_2	X	X	X	X	X	X
2	Kaolinite	$Al_2Si_2O_5(OH)_4$	X	X	X	X	X	X
3	Albite	$Na(Si_3Al)O_8$		X	X	X		
4	Coquimbite	$Fe_2(SO_4)_3.9H_2O$	X	X	X	X	X	X
5	Muscovite	$(K,Na)Al_2(Si,Al)_4O_{10}$	X	X	X	X	X	X
6	Gypsum	$CaSO_4.2H_2O$	X				X	
7	Anorthite	$(Ca,Na)(Si,Al)_4O_8$					X	

Note: Indices behind the name of the samples (T/B) indicate the sieving results, T is for top mesh size and B is bottom mesh size. Samples without indices indicate the samples did not undergo the sieving analysist.

(a) Sample PE$_T$ before (left) and after (right) simulation

(b) Sample PE$_B$ before (left) and after (right) simulation

(c) Sample Q10$_T$ before (left) and after (right) simulation

(d) Sample Q10$_B$ before (left) and after (right) simulatio

FIGURE 2. The Physical Comparison of The Samples Before (Left) and After (Right) Simulation

Leachate Analysis

According to the results of the weekly measurement of pH and electric conductivity (EC) of leachate, there were two characteristics of pH and EC [12] – [13]. Group 1 PAF intermediate capacity (IC) samples with intermediate values of kinetic pH (3-6) and electric conductivity. Q10 $_T$ and Q10$_B$ belonged to this group. The pH of Q10$_T$ and

Q10$_B$ leachates was gradually stable at 3.97 and 3.73, respectively. An increase in pH showed a reduction in sulfide mineral in the samples. Group 2 PAF high capacity (HC) samples with small pH values of kinetic pH (<3) and high electric conductivity. PE$_T$ and PE$_B$ belonged to this group. The pH of PE$_T$ and PE$_B$ leachates was gradually decreased, starting at 3.04 and 3.09, and dropped to 2.84 and 2.97 respectively. The low pH indicated the remaining sulfide mineral in the samples still experienced the oxidation. The presence of the silica minerals, i.e., Al and K in muscovite and Si in quartz, did not affect much on the pH. Figure 3 shows the pH and EC result during the simulations.

TABLE 4. The Classification of Static and Kinetic Test Results

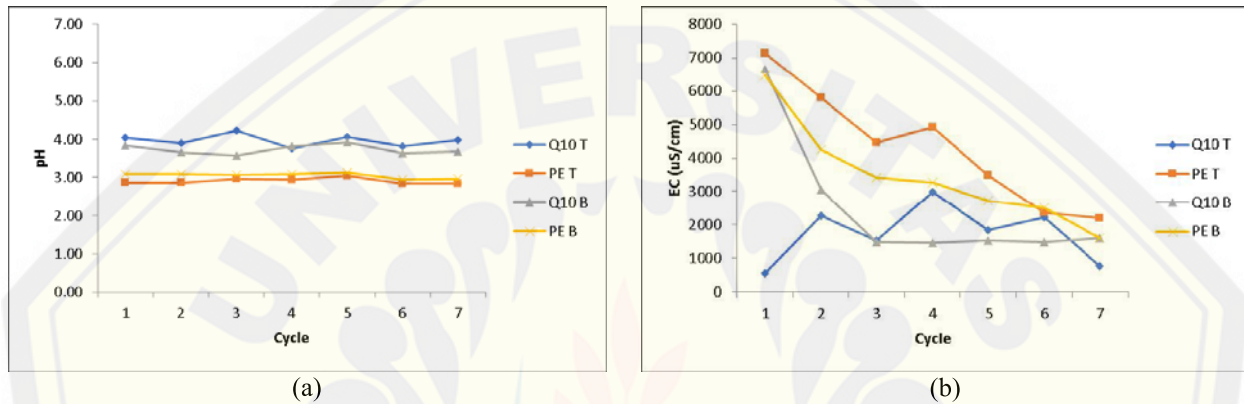| Sample	Static Classification	Kinetic Classification
PE	PAF	PAF HC
Q10	UC	PAF IC

(a)

(b)

FIGURE 3. The pH (a) and Electric Conductivity (b) Result of the samples
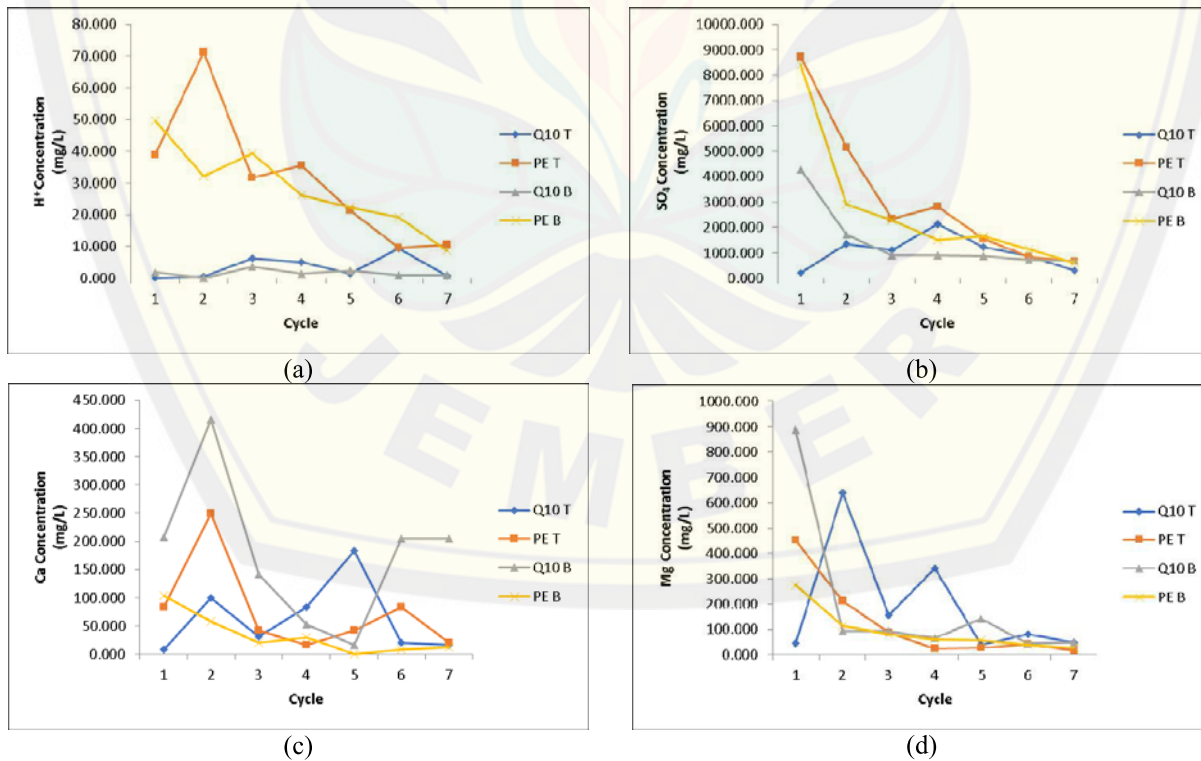

(a)

(b)

(c)

(d)

FIGURE 4. The Dissolved Metal Contents of The Leachates; Acidity (a), Sulfate (b), Calcium (c), and Magnesium (d)

Carbonate Dissolution and Pyrite Oxidation Rate

The determination of the weathering rate is essential in the kinetic test of acid mine drainage. In this research, the weathering rate was calculated based on the carbonate dissolution and pyrite oxidation rate. These two parameters were chosen since they were firmly related to the generation of the acid mine drainage and the neutralizing process [10]. EPA has shown the example of determining the carbonate dissolution and pyrite oxidation rate. The weathering results of the carbonate and pyrite were plotted into logarithmic and power graph. These two graphs are recommended to capture this process [14] – [15].
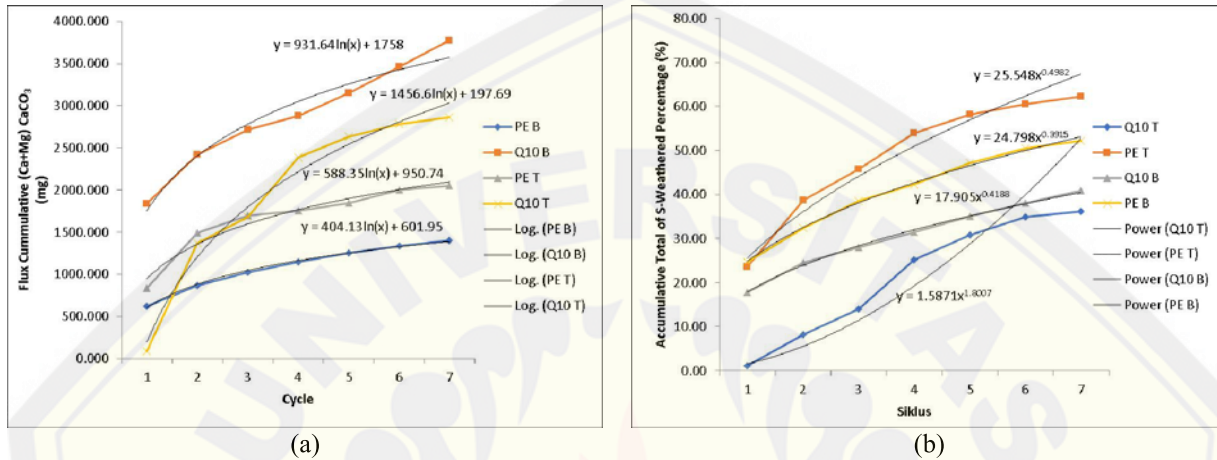

| (a) | (b) |

FIGURE 5. The graph of Flux Accumulative of $CaCO_3$ (a) and Accumulative total of S- Weathered Percentage (b)

The carbonate dissolution rate is presented as Mg and Ca dissolved metals [16]. Figure 5 (a) shows the carbonate dissolution rate. The cumulative rate of carbonate dissolution (mg $CaCO_3$) for PE_T, $Q10_T$, PE_B, $Q10_B$ at the end of the simulation was 2.048,1; 2.867,5; 1.401,5; and 3,776.6 respectively. Although the trendline of Mg and Ca dissolved metal contents were decreasing on the last day of the simulation, the Mg and Ca in the samples were not fully weathered and dissolved (see Fig. 4c and d). The remaining Mg and Ca minerals were still in the samples. This means that the neutralizing process was still undergoing, even for the extended simulation period.

The pyrite oxidation rate is presented as the amount of Sulphur weathered each cycle and then compared to the mass of the Sulphur in the samples [14]. Figure 5 (b) shows the accumulative Sulphur weathered during the simulation. The percentage accumulative Sulphur weathered for PE_T, $Q10_T$, PE_B, $Q10_B$ at the end of the simulation was 62.3%; 36.2%; 52.2%; and 40.9% respectively. The average of pyrite oxidation rate for PE_T, $Q10_T$, PE_B, $Q10_B$ was 8.9%; 5.2%; 7.5%; and 5.9% respectively.

According to the results above, it can be concluded about the oxidation rate of sulfide minerals through the comparison of the weathering rate of velocity between the weathering rate of sulfide minerals and the weathering rate of carbonates. These observations show the next weathering interpretation in the future. If sulfide weathers faster than carbonate, this condition shows that rock samples will produce higher alkalinity in the future so that rocks will be neutral more quickly, vice versa. If the carbonate weathers faster than sulfide minerals, then this condition shows that rock samples will produce less alkalinity in the future, so that rocks will produce acid over time and are difficult or require a long time to neutralize.
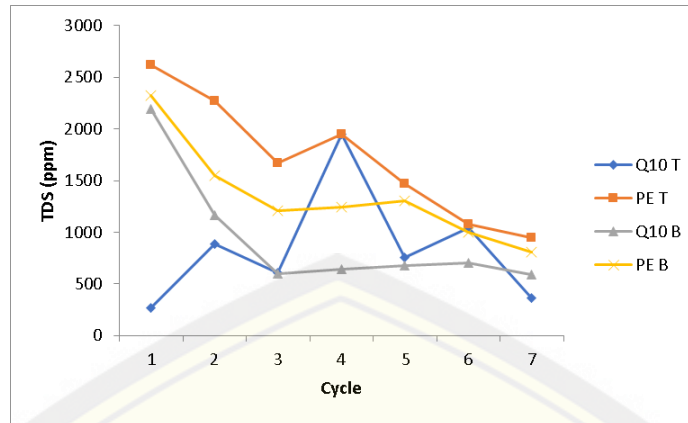
FIGURE 6. Total Dissolved Solids of The Leachates

The intensity of the weathering process can be indicated by the TDS (Total Dissolved Solids) parameter. TDS is related to paste pH on static tests. Generally, samples with lower paste pH will weather faster than the samples with higher paste pH. Figure 6 shows the total dissolved solids of the leachates during the simulations. PE samples have lower paste pH, thus from the figure, samples PE weathered faster than Q10.

CONCLUSION

Free draining humidity column test was conducted on four samples classified as potentially acid-forming and uncertain by static tests. The result of the 7-cycle (56-day) simulation was used to confirm the results of the static tests. The kinetic tests classified the sample PE as PAF high capacity and Q10 as PAF intermediate capacity. At the end of the simulations, the sulfate mineral (Coquimbite) and carbonate-silicate minerals (Kaolinite and Muscovite) still existed in the samples. The existence of the minerals in the last cycle indicated the undergoing pyrite oxidation and carbonate dissolution. The calculation of the carbonate dissolution and pyrite oxidation rate were performed with EPA Method 1627. The cumulative rate of carbonate dissolution (mg $CaCO_3$) for PE_T, $Q10_T$, PE_B, $Q10_B$ at the end of the simulation was 2.048,1; 2.867,5; 1.401,5; and 3,776.6 respectively. The remaining Mg and Ca minerals were still in the samples. This means that the neutralizing process was still undergoing, even for the extended simulation period. The percentage accumulative Sulphur weathered for PE_T, $Q10_T$, PE_B, $Q10_B$ at the end of the simulation was 62.3%; 36.2%; 52.2%; and 40.9% respectively. The average of pyrite oxidation rate for PE_T, $Q10_T$, PE_B, $Q10_B$ was 8.9%; 5.2%; 7.5%; and 5.9% respectively. This observation is useful to predict the quality of the future acid mine drainage whether sulfide weathers faster than carbonate. The intensity of weathering relates to the paste pH. PE weathered faster than Q10.

ACKNOWLEDGEMENT

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