



Waste rock characteristics at tropical coal mine area: A case study of PT. Kaltim Prima Coal, Indonesia

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ABSTRACT

Geochemical characteristics and the increase of total reactive surface area of the sulphide-bearing waste rock due to weathering processes at dumping area are expected to enhance the oxidation of sulphide minerals, commonly present as pyrite (FeS_2), leading to acid mine drainage (AMD) generation. Having investigated the geochemical characteristics of the waste rock at the surface layer (0 - 200 cm depth) of Pit J (2 years-old) and Sangatta North (10 years-old) dumping areas, the study indicated that the oxidation of sulphide-bearing waste rock uniformly occurred and it was influenced by the physical weathering as the forerunners of chemical weathering. The formation of clay minerals was then considered to have a potency of being oxygen and water barrier which consequently would reduce the AMD generation. In addition to that, an investigation of *in situ* waste rocks from Melawan area was also conducted. The results of investigation indicated that the rocks were physically easy to break down hence increasing the total reactive surface area for chemical reaction upon exposed to the climatic condition, and should be considered as an important factor in determining the processes of AMD generation afterward at dumping area.

Keywords: geochemical, acid mine drainage, dumping, waste rock, weathering

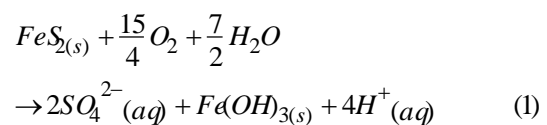
1. INTRODUCTION

Acid mine drainage (AMD) has been acknowledged by some ore mining and most coal mining operations being one of the main problems associated with environmental concern. Many studies have been conducted concerning the issues of AMD generation, encompassing the topics about identification of the sources (Sracek et al., 2004; Munk et al., 2006), the processes and the influence factors (Singer and Stumm, 1979; Sasaki et al., 1989; Lefebvre et al., 2001; Newbrough and Gammons, 2002), prevention methods (Frostad et al., 2005; Yanful et al., 2006), and the treatment (Ziemkiewicz and Skousen, 1996).

The factor of rock chemistry or geochemistry plays an important role in determining the process of AMD generation in relation to the existence of potentially acid forming materials and also acid buffering or neutralizing materials.

Rock weathering, physically and chemically, is one of the processes that occur at the waste rock that is affected by the local climatic condition, especially rainfall and temperature. Physical weathering process is generally the forerunners of chemical weathering thus contribute to loosen rock masses, reduce the size of particles, and increase the reactive surface area for chemical reactions (Mitchell, 1976).

The increase of reactive surface area of sulphide-bearing waste rock will accelerate the oxidation rate of AMD generation (Davis and Ritchie, 1987; Devasahayam, 2006). In general, pyrite (FeS_2), a sulphide mineral that is commonly found on the waste rock and typical of many oxidation processes during weathering (Keller, 1957), is oxidized in accordance with the following reaction (Sengupta, 1993):



Having said that, this study was particularly intended to know the characteristic of the *in situ* waste rock and waste rock at dumping area as an indicator of rock weathering occurrences. Understanding these conditions will be useful for investigating the potency and occurrence of pyrite oxidation that has obvious impact on AMD generation.

2. SITE DESCRIPTION

PT. Kaltim Prima Coal (KPC) is the biggest open pit coal mine in Indonesia, and the third in the world, located in Sengata – East Kalimantan, Indonesia. The location has a

tropical climate with high average seasonal rainfall varying from 1.6 to 2.5 metres annually and average temperature varying from 26 to 32°C. Until the end of 2008, KPC had cleared 126.3 x 10⁶ m² of land for mining activities including supporting facilities, and had rehabilitated 32.8 x 10⁶ m² of the area. The coal production in 2008 reached around 37.5 million tons.

The sedimentary coal sequence at KPC mine area has a variety of sedimentary rock types and includes horizons that are known to be pyretic and those that contain acid producing materials. Pyrite in the KPC mine sequence primarily occurs in the material just (approximately 2m in thickness) at immediate roof and floor of the coal seams.

The areas used for the study were Melawan, Pit J, and Sangatta North (Figure 1). The samples of Melawan area were obtained from the boreholes of exploration activities, out of pit and dump area, whereas the samples of Pit J and Sangatta North were from the test pit of dump areas. There was no data exactly mentioned the relationship between Melawan and both Pit J and Sangatta North samples in lithology and geochemical aspects. In addition, there was no relationship between Pit J and Sangatta North samples, since the determination of the location was based on the ages of dumping area. Thus, the study was intended to know the conditions of geochemical and physical considering different ages of exposure to the climate conditions, and their influences to the AMD generation, as has been introduced previously.

3. METHODOLOGY

3.1 Field investigation

The *in situ* waste rock samples were obtained from the boreholes of exploration activities at Pit Melawan in February – May 2008, named as F24088 (14 samples), F27029 (8 samples), F27030 (13 samples), and F27043 (9 samples) until around 150 m depth, with an interference of coal seam at 115 – 126 m depth. The samples represent the material with same lithology types from several layers. Having investigated for geological purposes, the rock samples were obtained from each borehole based on lithological condition for geochemical and physical investigation purposes.

On the other side, investigation of waste rock at dumping area was conducted at Pit J (2 years old) and Sangatta North (10 years old) at 0 – 2 meters depth.

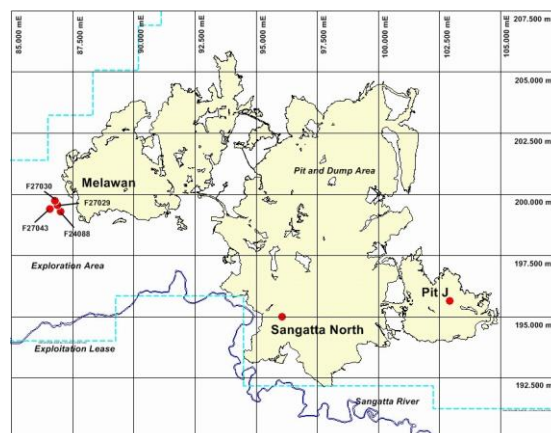
The waste rock samples were obtained from two holes of 2 x 2 x 2 meters which were excavated each at flat areas (Figure 2). An amount of 5 kg of rock samples were taken from each 20 cm interval depth, and subsequently divided into 4 quadrants. One quadrant of samples was afterward dried, crushed, and pulverized under 75 µm in diameters for the laboratory examinations.

3.2 Laboratory analysis

Geochemical analyses of rock samples were conducted to predict whether a rock sample has acid producing and/or acid neutralizing capacity (Blowes et al., 2003), consisted of Net Acid Generation (NAG) test, Paste pH, Paste EC and Acid Neutralizing Capacity (ANC).

Beside those methods, mineralogy study with Rigaku RINT 2000 X-Ray Diffractometer (XRD) and elemental

compositions analysis with Rigaku RIX 3100 X-Ray Fluorescence (XRF) spectrometer were also carried out. Total sulfur obtained from XRF analysis was used to determine Maximum Potential Acid (MPA in kg H₂SO₄/ton = 30.6 x % Sulphur), and Net Acid Production Potential (NAPP) value is determined from the difference values of MPA and ANC subsequently.



* grid in UTM Zone 50; North Hemisphere (WGS 84)

Figure 1. Location of study



Figure 2. Waste rock sampling activities at Pit J

A. NAG Test

NAG test was conducted based on the procedure compiled by KPC from Environmental Geochemistry International Pty. Ltd. procedure, where a 2.5 gram of rock samples is reacted with 250 mL of 7.5% hydrogen peroxide (H₂O₂) 12 – 16 hours and then followed by heating for 30 minutes. Having mixed this rock sample with sodium hydroxide (NaOH), the NAG pH is then measured (KPC, 2003).

B. Paste pH and Paste EC

Paste pH and Paste EC are used to show the existence of current result of sulphide mineral oxidation. The paste is prepared by soaking the rock sample for 16 hours in a ratio of water to rock sample as 2 : 1 (AMIRA, 2002)

C. ANC test

ANC test is used to determine the capacity of rock to neutralize the acidity (in kg H₂SO₄/ton). Two gram of crushed rock samples are reacted by heating in the presence of known

concentrations of hydrochloric acid (HCl), which is determined from Fizz test. The solution then is titrated with known concentration of sodium hydroxide (NaOH) with addition of hydrogen peroxide (H_2O_2) at near to pH 5. The ANC then is determined based on the quantities and concentration of HCl and NaOH used (AMIRA, 2002).

Following the investigation of geochemical characteristics, the physical characteristics of *in situ* rock samples were also tested for the parameters of strength, moisture and density, whereas liquid limit (LL) and Plastic Limit (PL) of soil (often collectively referred to as the Atterberg Limits) and clay content analyses were applied for the samples from dumping area, based on ASTM D4318 and hydrometer analyses procedures, respectively. Plasticity Index (PI) was then determined, as the difference between the Liquid Limit and the Plastic Limit ($PI = LL - PL$). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 tend to have little or no silt or clay.

4. RESULTS AND DISCUSSION

4.1 *In situ* waste rock

Total 44 of samples were obtained from Pit Melawan (Table 1) and analyzed with NAG test. Furthermore, having combined these values with the values of NAPP, the classification of rock samples was determined, resulting 20 of samples had $NAG\ pH \geq 4$ and 21 samples had $NAG\ pH < 4$. Only three samples were identified and classified as "uncertain" (UC) due to the conflict between NAG pH and NAPP values. However, considering the un-significance of NAPP values of those samples to the determination-limit value ($0\ kg\ H_2SO_4/ton$), the classification of those samples can be done using their NAG test values.

In general, the results indicated that the area of study had both NAF and PAF materials. The presence of PAF particularly indicated the potency of AMD generation if they are not being handled properly during removal and dumping activities, which is caused by the oxidation processes in the presence of water, commonly from the rainfall. However, this potency of AMD generation possibly can be altered by the availability of neutralizing capacity, especially from NAF material. The results of investigations indicated that PAF materials had neutralizing capacities. However, the amount is less than the acid potential. In addition to that, the neutralizing capacity will dissolve faster than sulphide minerals (Blowes et al., 2003).

The presence of neutralizing capacity can be observed by the relationship between NAG pH and Paste pH. Figure 3 indicates that almost all of the samples have Paste pH values greater than those of NAG pH, meaning those samples have not fully oxidized yet and still have neutralizing potency particularly from the carbonate minerals. Sample contains reactive sulphide minerals (such as framboidal pyrite) will apparently be the most responsive in Paste pH test and resulting low pH value (Stewart, 2007).

In relation to the increase of potency of AMD generation due to physical weathering occurrences, the investigation resulted that based on Hoek and Brown classification (1997), the rock samples were classified as "very weak" to "weak" rock, and stated as "highly weathered or altered rock".

Bieniawski (1989) classified those samples as soft rock, since the UCS values are less than 20 MPa. Kramadibrata et al (2009) mentioned that soft rock is described as geomaterials with properties between soil and rock, and in Indonesia, environmental changes such as cyclical drying and wetting condition have been believed to lead to deterioration of the mechanical properties of the rock. Table 2 shows the values of Uniaxial Compressive Strength (UCS), and Table 3 shows moisture and bulk density values.

Table 1. Classification of rock samples

Hole	Depth (m)		Lithology	NAG pH	NAPP*	Paste pH	Type
	From	To					
F24088							
2	6.00	9.00	SS	2.9	4.2	4.7	PAF
9	20.45	20.95	SS	5.8	-45.0	7.3	NAF
14	30.10	33.20	MS	3.3	1.6	5.9	PAF
17	37.92	39.25	MS	5.8	-29.1	6.0	NAF
20	40.98	42.42	MS	3.0	0.1	5.9	PAF
33	63.30	65.05	MS	5.6	-3.8	6.8	NAF
48	85.61	85.85	MS	2.7	2.3	5.0	PAF
50	87.30	90.30	MS	5.1	-2.2	6.1	NAF
53	92.52	93.30	MS	2.3	5.9	4.8	PAF
58	105.30	106.80	MS	4.5	-2.8	6.4	NAF
62	113.57	114.13	SS	2.3	42.5	3.7	PAF
67	129.23	129.57	SL	4.6	-18.4	6.9	NAF
75	139.70	140.26	SS	2.1	29.4	4.0	PAF
79	144.99	145.44	MS	4.8	-14.2	6.1	NAF
F27029							
15	26.87	28.62	MS	5.4	-5.4	7.4	NAF
38	65.27	65.72	MS	3.0	1.2	6.2	PAF
47	80.04	83.22	MS	4.6	-3.2	6.4	NAF
57	101.87	103.95	MS	2.7	8.8	4.2	PAF
60	111.12	113.14	MS	4.6	-1.7	5.2	NAF
63	119.06	124.92	MS	2.9	6.4	4.4	PAF
65	134.22	134.89	MS	3.8	-0.8	5.1	NAF
69	140.82	142.77	MS	3.0	5.8	4.8	PAF
F27030							
2	3.00	6.25	MS	3.0	2.5	5.2	PAF
7	13.25	15.25	MS	4.6	-2.4	6.4	NAF
14	24.51	25.35	MS	3.1	2.9	5.0	PAF
21	32.97	33.25	SS	4.8	-3.3	5.9	NAF
37	59.38	59.75	MS	2.6	5.3	5.2	PAF
38	60.00	62.20	MS	4.6	-5.6	6.4	NAF
42	67.25	68.60	SS	3.0	3.7	5.5	PAF
44	69.49	71.78	MS	4.8	-1.4	5.7	NAF
46	73.25	73.50	SS	2.3	8.1	4.6	PAF
49	74.60	76.85	SS	4.8	-3.3	6.6	NAF
58	99.25	100.35	SS	2.5	4.1	4.6	PAF
67	128.97	129.60	MS	4.6	-7.0	7.3	NAF
77	139.32	140.07	MS	2.9	-1.4	6.6	UC
F27043							
4	9.27	10.17	SS	7.5	2.6	6.0	UC
10	24.27	26.87	SS	3.2	9.5	5.2	PAF
13	33.02	33.27	MS	6.1	2.9	6.6	UC
17	39.06	39.30	SL	3.2	4.0	5.0	PAF
41	75.27	77.72	MS	7.8	-3.7	6.6	NAF
56	105.27	106.17	SS	2.3	12.4	4.3	PAF
60	113.72	115.55	SS	4.6	-2.0	6.0	NAF
62	116.22	116.72	SS	3.0	9.0	4.4	PAF
71	139.36	139.99	SL	6.7	-2.4	6.9	NAF

Classification:

NAF: $NAG\ pH \geq 4$; $NAPP \leq 0$; PAF: $NAG\ pH < 4$; $NAPP > 0$

UC: $NAG\ pH \geq 4$; $NAPP > 0$; or $NAG\ pH < 4$; $NAPP \leq 0$

NAPP in $kg\ H_2SO_4/ton$

SS: sandstone; MS: mudstone; SL: siltstone

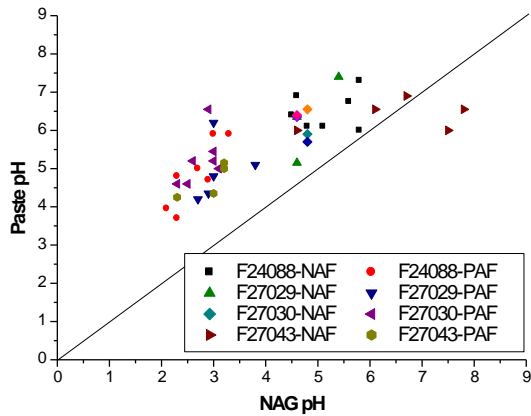


Figure 3. Relationship between Paste pH and NAG pH

Table 2. UCS values of *in situ* rock samples

Lithology	Total samples	UCS (MPa)			
		Min	Max	Avg	σ
Sandstone	13	0.31	5.72	1.80	0.70
Mudstone	52	0.11	2.98	1.35	3.37
Siltstone	13	0.82	11.12	3.48	1.45

Table 3. Moisture and bulk density values of *in situ* rock samples

Lithology	Total samples	Moisture (%)		Bulk density (kg/m ³)	
		Avg	σ	Avg	σ
Sandstone	13	11.18	2.32	2,219	106
Mudstone	52	10.90	1.78	2,276	74
Siltstone	13	7.95	1.52	2,378	73

Furthermore, chemical rock weathering also took place strongly according to the classification by Peltier (1950) based on the rainfall and temperature condition of the study area.

Having considered the results of geochemical and physical characteristics of *in situ* waste rock, the processes of AMD generation will be fast upon exposed to the climatic condition during coal mining operation.

4.2 Waste rock at dumping area

Physically, the rock samples obtained from both Pit J and Sangatta North were dominated by soft rock with little boulders, indicated the occurrences of physical rock weathering at dumping area. In addition to that, 10 samples obtained from Pit J geochemically had Paste pH greater than 4, and 6 samples of those had NAG pH less than 4. The differences of Paste pH and NAG pH indicated that the samples still had a considerable amount of neutralizing minerals, and they were still in the initial stage of AMD generation that have possibilities to further oxidize. This result was different for the samples obtained from Sangatta North where 5 samples had Paste pH less than 4, and 7 samples which had NAG pH less than 4 (Figure 4).

In general, NAG pH and Paste pH values in each dump showed that no NAG pH and Paste pH changes with depth observed, except for the samples of Pit J from 20 – 40 cm depth and Sangatta North from 00 – 20 cm, 140 – 160 cm and 180 – 200 cm depth. These results indicated the uniformity of chemical weathering processes at each dump.

In addition, the differences between NAG pH and Paste pH values at Pit J and Sangatta North were generally consistent. Except for those samples mentioned above, it therefore can be stated that Pit J had higher gap of pH value compared with Sangatta North. This condition is attributed to the fact that oxidation process at Sangatta North had advanced further than at Pit J, resulting low neutralizing capacity.

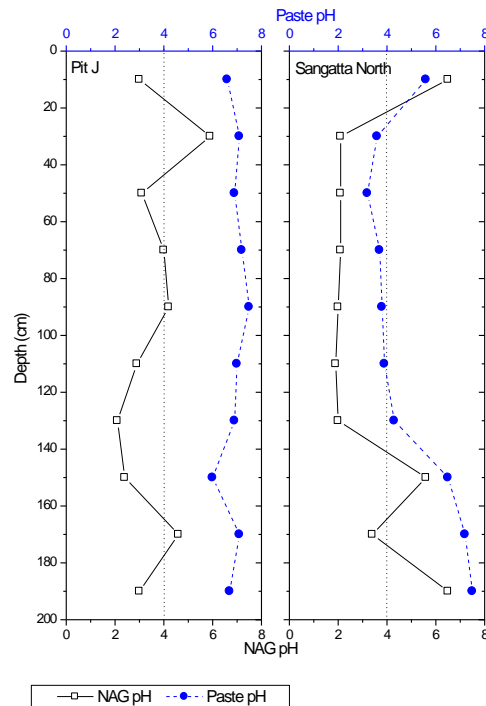


Figure 4. NAG pH and Paste pH values versus depth in Pit J and Sangatta North

The different oxidation levels can also be seen from the comparison between Paste pH and Paste EC (Figure 5). Paste pH from Pit J showed a neutral condition and tended to correlate with Paste EC. It indicated that the alkalinity on the rock samples was still present. During the weathering processes, the alkalinity reacted with hydrogen and sulfate ions that were resulted from pyrite oxidation, decreasing the total ions because of precipitation.

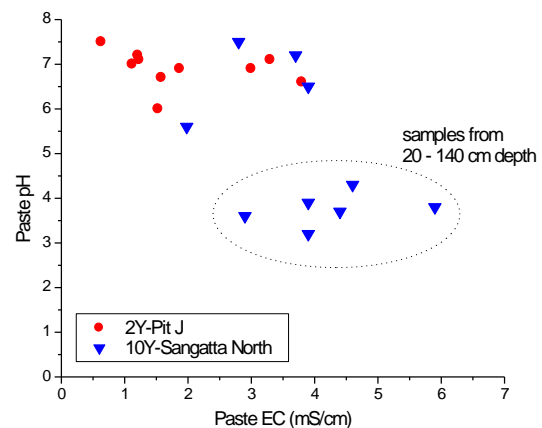


Figure 5. Paste pH versus Paste EC

On the contrary, Sangatta North samples had Paste EC that varied from 2 – 5.9 mS/cm, and low Paste pH due to lack of alkalinity, as shown by ANC values, especially for the samples at 20 – 140 cm depth (Table 4).

Considering NAG pH and NAPP values, the samples obtained from Pit J at 60 – 80 cm, 80 – 100 cm, and 160 – 180 cm depth and from Sangatta North at 180 – 200 cm depth were NAF whereas samples obtained from Pit J at 20 – 40 cm and from Sangatta North at 00 – 20 cm and 140 – 160 cm depth were classified as “uncertain (UC)” since there was a conflict between NAG pH and NAPP values. The other samples were classified as PAF. Consequently, the samples from Pit J and Sangatta North still have the possibility to further oxidize though they are 2 and 10 years old.

Table 4. Static test results of the samples.

Sample	Depth (cm)	NAG pH	MPA	ANC	NAPP	Type
2Y – Pit J	00-20	3.0	20.5	9.6	10.9	PAF
	20-40	5.9	16	15.2	0.8	UC
	40-60	3.1	17.7	11.7	6	PAF
	60-80	4.0	6.6	8.7	-2.1	NAF
	80-100	4.2	6.6	8.4	-1.9	NAF
	100-120	2.9	14.2	12	2.3	PAF
	120-140	2.1	34.7	18.2	16.5	PAF
	140-160	2.4	28	12.2	15.8	PAF
	160-180	4.6	7.5	11.1	-3.6	NAF
	180-200	3.0	20.1	15	5.1	PAF
10Y - Sangatta North	00-20	6.5	28.6	25.9	2.7	UC
	20-40	2.1	62.5	-8.7	71.2	PAF
	40-60	2.1	72.1	-14.2	86.3	PAF
	60-80	2.1	70.5	-9.3	79.8	PAF
	80-100	2.0	88.4	-6.6	95	PAF
	100-120	1.9	69.5	-10.3	79.8	PAF
	120-140	2.0	48.6	-5.7	54.3	PAF
	140-160	5.6	15.6	9.1	6.5	UC
	160-180	3.4	20.9	12.3	8.6	PAF
	180-200	6.5	14.5	18.1	-3.6	NAF

Maximum Potential Acid (MPA) = 30.6 X % Total Sulfur (S)

Net Acid Potential Production (NAPP) = MPA – ANC

MPA, ANC, NAPP in kg H₂SO₄/ton

NAF : NAG pH ≥ 4; NAPP ≤ 0

PAF : NAG pH < 4; NAPP > 0

UC : NAG pH ≥ 4; NAPP > 0; or NAG pH < 4; NAPP ≤ 0

Mineralogical examination was conducted for the samples at 00 – 20 cm, 40 – 60 cm, and 180 - 200 cm depths for each dump. The minerals of quartz (SiO₂), kaolinite (Al₂Si₂O₅(OH)₄), illite ((K,H₃O)Al₂Si₃AlO₁₀(OH)₂), illite-montmorillonite (KAl₄(Si,Al)₈O₁₀(OH)₄·4H₂O), and siderite (FeCO₃) were observed on the samples.

Furthermore, there were differences of secondary mineral compositions as the results of pyrite oxidation. At the surface of Pit J, the secondary mineral observed was melanterite (Fe^{II}SO₄·7H₂O) whereas gypsum (CaSO₄) was only at Sangatta North. This result was consistent with previous study where melanterite is the dominant mineral to be precipitated during the initial stages of sulphide oxidation (Nordstrom, 1982). Jarosite (KFe₃(SO₄)₂(OH)₆), a secondary mineral with bright yellow to brown color and occurs as an alteration product when pyrite is in contact with sulfate-rich water, was observed at the samples of Pit J and Sangatta North.

The mineralogy study concluded that the abundances of

clay minerals (illite, kaolinite, montmorillonite) at Pit J and Sangatta North were an indication that the waste rocks had weathered formerly, and at the dump sites, the weathering processes continued and they were accelerated under the influence of climatic conditions.

In addition to the results above, Atterberg Limits analyses for fine-grained samples (ASTM D4318-00) showed that the samples obtained from Pit J and Sangatta North were classified as “CL”, meaning “inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays”, based on the criteria of the Unified Soil Classification System (USCS) (Figure 6) and the average clay contents at Pit J and Sangatta North were 11.1% and 32.4%, respectively (Table 5).

Table 5. Results of texture analyses

Location	Depth (cm)	Clay	Silt	Sand
Pit J	00 - 20	11.9	59.1	29
	40 - 60	10.8	62.2	27
	180 - 200	10.7	56.2	33.1
	Average	11.1	59.2	29.7
Sangatta North	00 - 20	30.3	37.7	32
	40 - 60	24.4	26.6	48.9
	180 - 200	42.4	34.6	23
	Average	32.4	33.0	34.6

The presence of clay minerals, even a small amount, can control the permeability and water retention characteristics of porous media and very sensitive to the pore-water chemistry thus limiting the flux of water and oxygen into and within the dump for the processes of pyrite oxidation (Bowell, 2006).

Therefore, it could be suggested that the uncompleted oxidation at Pit J was mainly caused by the presence of adequate neutralizing minerals, and the uncompleted oxidation of Sangatta North was mainly caused by an inadequate presence of oxygen as a consequence of physical characteristics changes due to weathering i.e. natural compaction of the surface layer and high water content (9.8 – 17.6%), in conjunction with releasing the neutralizing potency.

In general, the characteristics of *in situ* waste rocks and waste rocks at dumping area are summarized on Table 6.

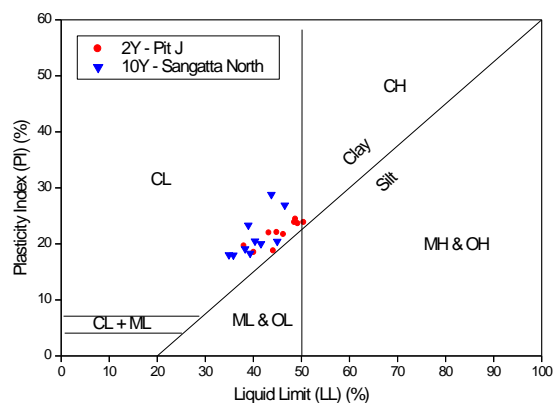


Figure 6. Plasticity chart of Pit J and Sangatta North samples

Table 6. Summary of waste rock characteristics

Characteristic	In situ	2 years old	10 years old
Geochemical			
• Type of rock	NAF and PAF	NAF and PAF	NAF and PAF
• Oxidation	No	Yes	Yes – Advance
• Neutralizing potency	Available	Available	Less available
• Weathering condition	Weathered	Weathered	Weathered
Physical			
• Strength	Very weak	Very weak/ Soft rock	Very weak/ Soft rock
• Clay	Observed	Observed	Observed

5. CONCLUSION

In situ waste rocks at Melawan showed the potency of AMD generation in the future upon exposed to the climate condition. The processes of AMD generation will be fast due to physical condition of rock that was classified as soft rock, meaning that the rock is physically easy to break down hence increasing the total reactive surface area for chemical reactions.

On the other side, the study of waste rock at dumping area showed the differences in oxidation progress between Pit J dump (2 years old) which was still in the initial stage of AMD generation, and Sangatta North dump (10 years old) which was more advanced. These conditions were also indicated by physical and chemical weathering occurrences.

Furthermore, it can be suggested that rock weathering possibly can decrease the potency of AMD generation at dumping area by creating finer size of particles and clay minerals that can act as a barrier against oxygen diffusion and water infiltration. However, during the weathering processes, the oxidation of pyrite will still occur due to increasing of total reactive surface area, and it should be taken into consideration.

It is important to conduct further investigation about weathering, its effect to the oxidation processes and engineering applications to prevent or minimize AMD generation, including optimization the potency of *in situ* material considering its physical and geochemical characteristic.

REFERENCES

AMIRA International, 2002. *ARD Test Handbook*, Australia

Bieniawski, Z. T., 1989. *Engineering rock mass classification*, New York, John-Wiley Press.

Blowes, D. W, Ptacek, C. J., Jambor, J. L., Wisener, C. G., 2003. *Treatise on Geochemistry Vol. 9*, B S Lollar (Ed.), Elsevier, 149 – 204.

Bowell, R. J., Sapsford, D. J., Dey, M., Williams, K. P., 2006. Protocols affecting the reactivity of mine waste during laboratory-based kinetic test. In: *Proceeding of 7th International Conference on Acid Rock drainage (ICARD)*, St. Louis MO. R. I. Barnhisel (ed.) Published by the American Society of Mining and Reclamation (ASMR), 3134 Montavesta Road, Lexington, KY 40502.

Davis, G. B., Ritchie, A. I. M., 1987. A model of oxidation in pyrite

mine waste: part 3: import of particle size distribution, *Applied Mathematical Modelling*, **11**, 417 – 422.

Devasahayam, S., 2006. Application of particle size distribution analysis in evaluating the weathering in coal mine rejects and tailings, *Fuel Processing Technology*, **88**, 295 – 301.

Frostad, S., Klein, B., Lawrence, R. W., 2005. Determining the weathering characteristics of a waste dump with field tests, *International Journal of Surface Mining, Reclamation and Environment*, (19), **2**, 132 – 143.

Hoek, E. and Brown, E. T. 1997. Practical estimates of rock mass strength, *International Journal of Rock Mechanics and Mining Sciences*, (34), **8**, pp. 1165-1186

Keller, W. D., 1957. *The principles of chemical weathering*, Columbia, Missouri, Lucas Brothers Publisher.

Kramadibrata, S., Saptono, S., Wicaksana, Y., Prasetyo, S. H. 2009. Soft rock behaviour with particular reference to coal bearing strata. *Proceeding of 2nd International Symposium of Novel Carbon Resource Science*, Joint Symposium Kyushu University – Institut Teknologi Bandung.

Lefebvre, R., Hocklye, D., Smolensky, J. Gelinias, P., 2001. Multiphase transfer processes in waste rock piles producing acid mine drainage 1: conceptual model and system characterization, *Journal of Contaminant Hydrology*, 137 – 52.

Mitchell, J. K., 1976. *Fundamentals of soil behavior*, University of California, Berkeley, John Wiley & Sons, Inc.

Munk, L., Faure, G., Koski, R., 2006. Geochemical evolution of solutions derived from experimental weathering of sulfide-bearing rocks, *Applied Geochemistry*, **21**, 1123 – 1134.

Newbrough, P., Gammons, C. H., 2002. An experimental study of water-rock interaction and acid rock drainage in the Butte mining district, Montana, *Environmental Geology*, **41**, 705 – 719.

Nordstrom, D. K., 1982. Aqueous pyrite oxidation and the consequent formation of secondary iron minerals, *Acid Sulfate Weathering*, Soil Science of America Press, 37-56.

Peltier, L. C., 1950. The Geographic Cycle in Periglacial Regions as it is Related to Climatic Geomorphology, *Annals of the Association of American Geographers*, **40**, 214 – 236.

PT. Kaltim Prima Coal (KPC), 2003. *NAG Test Manual*

Sasaki, K., Tsunekawa, M., Ohtsuka, T., Konno, H., 1989. The role of sulfur-oxidizing bacteria *Thiobacillus thiooxidans* in pyrite weathering, *Colloids and Surfaces, A: Physicochemical and Engineering Aspects*, **133**, 269 – 278.

Sengupta, M., 1993. *Environmental Impacts on Mining – Monitoring, Restoration and Control*, Lewis Publisher.

Stewart, W., 2007. *Development of Acid Rock Drainage Prediction Methodologies for Coal Mine Wastes*, Dissertation, Ian Wark Research Institute University of South Australia.

Singer, P. C., Stumm, W., 1979. Acidic Mine Drainage: The Rate-Determining Step, *Science*, **167**, 1121 – 1123.

Sracek, O., Choquette, M., Gelinias, P., Lefebvre, R., Nicholson, R. V., 2004. Geochemical characterization of acid mine drainage from a waste rock pile, Mine Doyon, Quebec, Canada, *Journal of Contaminant Hydrology*, **69**, 47 – 71.

Yanful, E. K., Mousavi, S. M., Souza, L. P. D., 2006. A Numerical Study of Soil Cover Performance, *Journal of Environmental Management*, **81**, 72-92.

Ziemkiewicz, P. F., Skousen, J., 1996. Acid Mine Drainage Control and Treatment – Section 2. Treatment of Acid Mine Drainage, West Virginia, West Virginia University and the National Mine Land Reclamation Center Morgantown.