Comparison of Pit Wall Leaching Test in the Field and Laboratory

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Abstract

Mining activities will eventually end, while one of the options for the use of post-mining land is to make it a pit lake. To ensure the management of the pit lake in the future, it requires a study about geochemistry of the water to be formed. Quality of the developing water is results in the reaction between water and rock on pit wall. This research was conducted with the aim of identifying quality of the water to be formed. To determine quality of the water, a direct test was conducted in the field using the pit wall leaching method. The location of this test was in PT Kaltim Prima Coal, one of the largest coal producers in Indonesia. There were three locations considered to represent rock stratification exposed on the pit wall. Dimensions in test was 1 x 1 meter, while leachate yield was 2 liters. Test cycle was conducted in daily, three-day, and weekly cycles. Based on the result of static tests, sample A was classified as NAF rock, while samples B and C were classified as PAF rock. Meanwhile, leachate test shows the result that range of pH values was from 7.61 to 8.02 for sample A, from 1.99 to 2.77 for sample B, and from 2.89 to 4.09 for sample C. Based on test result, the most dominant metals were SO4, Mg, and Fe. The conclusion of this research is that the exposed rock on pit wall is dominated by PAF rock, thus having a potency to form acid mine drainage.

Keywords: Pit wall leaching, Geochemical characterization, Acid mine drainage

Introduction

Mining activities will end, while the final pit can be backfilled at mines having more than one pit or multi-pit. In some cases, formermining pits cannot be backfilled and are used as postmining lakes, termed mine pit lakes or pit lakes (Blanchette and Lund, 2016) (Castendyk, Eary and Balistrieri, 2015) (Vandenberg and Litke, 2018). One factor that needs to be considered during the process of forming a pit lake is quality of the water that will be formed. This is related to the continued use of pit lake. The water formed can be acidic or alkaline. The acid mine drainage formed affects the surrounding environment (Akcil and Koldas, 2006) (Blodau, 2006) (Acharya and Kharel, 2020). Issues of acid mine drainage in pit lakes can be seen for example in coal mining areas in Lusatia District, Germany (Gerke, Molson and Frind, 1998) and gold mining in the Iberian pyrite belt (Cánovas *et al.*, 2015) (Sánchez España *et al.*, 2005). Considering the impact brought by acid mine drainage, it is necessary to predict quality of the pit lake water that will form.

Acid mine drainage is caused by the oxidation of rocks containing sulfide minerals and the presence of water. Acid mine drainage is characterized by a pH value below 6. In addition to a low pH value, acid mine drainage also contains metals, namely Fe and Mn. Reaction for the formation of acid mine drainage is shown in formula as follows (Kefeni, Msagati and Mamba, 2017):

$$2FeS_2(s) + 2H_2O + 7O_2(aq) = 2Fe^{2+} + 4SO^{2-} + 4H^+ \quad (1)$$

$$4Fe^{2+} + 4H^+ + O_2 = 4Fe^{3+} + 2H_2O \quad (2)$$

$$Fe^{3+} + 3H_20 = Fe(OH)_3(s) + 3H^+ \quad (3)$$

$$FeS_2(s) + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO^{2-} + 16H^+ \quad (4)$$

Several factors that need to be considered in predicting pit lake water quality include groundwater inflow, precipitation, evaporation, pit wall runoff, rock wall washing (Castendyk, Eary and Balistrieri, 2015), biological processes, lake hydrodynamics, and geochemical equilibrium (Eary, 1999). Regarding rock wall washing, what needs to be done at an early stage is to determine the distribution of rocks forming acid mine drainage and rocks without potency to form acid mine drainage. Geochemical characterization of these rocks can be performed by running a series of tests. Tests in the field can be conducted using the pit wall leaching method, while test in the laboratory can be carried out using several tests, including mineralogy, static and kinetic tests (Castendyk, Mauk and Webster, 2005).

Pit wall leaching test was conducted using Minewall approach to estimate the geochemical effects of pit walls. Minewall was developed as a formal standard technique for Canadian MEND Program in the 1990s (Morin and Hutt, 2001). The application of this method has been carried out in several mining locations, such as Indonesia (Kusuma *et al.*, 2020), which was carried out in coal mines. Only in this study, the pit wall leaching test was tested once. In ore mining, the application of the Minewall method is carried out by (Andrade and Mountjoy, 2015). Compared to static and kinetic tests in the laboratory, with pit wall test it is better to obtain an overview of the water quality that will be formed, because it is directly carried out on exposed rock walls.

At the end of mining, quality of the water that will be formed must be predictable. One way to predict water quality is to determine the quality of leachate which is the reaction of rainwater and rocks on the pit walls. This research was conducted to comprehend the quality of water that will be formed and to compare hydrogeochemical tests carried out in field and laboratory. The results that have been obtained were then used to zoning the distribution area of PAF and NAF rocks which can finally simulate the prediction of water quality of the pit lake that will be formed.

Method

This research was conducted in the Peri pit which is the Coal Contract of Work area of PT. Kaltim Prima Coal (Figure 1) (Tuheteru *et al.*, 2021). Mining in Pit Peri has been carried out since 2010 and still continues to date. The mining plan ended in 2021. Pit Peri has 5 coal seams with a thickness from 0.54 to 3.42 meters. The planned coal production from 2010 to 2021 is approximately 6.5 million tons with a stripping ratio of 9.02. Pit wall leaching tests were carried out on mining pit walls in three locations with codes A, B, and C. The lithology of three samples was different, namely claystone, mudstone, and sandstone. Location A was dominated by clay rocks at an elevation of 60 - 70 masl, location B had organic elements because of coal layer at an elevation of 50 masl, while location C was dominated by sandstone, located the same with location B, at an elevation of 50 masl (Figure 2).

The research was conducted by applying mine wall or pit wall leaching method. The application of this method is very suitable for active mines, because pit walls are still open and will be reactive with water, making leachate water samples capable of being taken easily. This method was designed for the prediction of pit lake water quality as required for mine closure assessment (Andrade and Mountjoy, 2015). The procedure for this test was conducted from the development of a procedure by (Morin and Hutt, 2004). The pit wall leaching test was carried out by cleaning the rock surface first, until obtaining a fresh rock sample surface. Dimensions of the pit wall surface tested were 1 m2. Distilled water, inserted into sprayer with a capacity of two liters was used for watering the pit wall. Leachate from the spray was collected in a container. This reservoir was also used to collect leachate resulting from washing using rainwater. Location C was not carried out of shelter, because the rock surface was hard. The collected leachate was then put into a sample bottle with a capacity of 2 liters and taken to a laboratory owned by PT Kaltim Prima Coal for water physical testing. Besides physical tests, metal content tests were also carried out in laboratories which are partners of PT Kaltim Prima Coal.

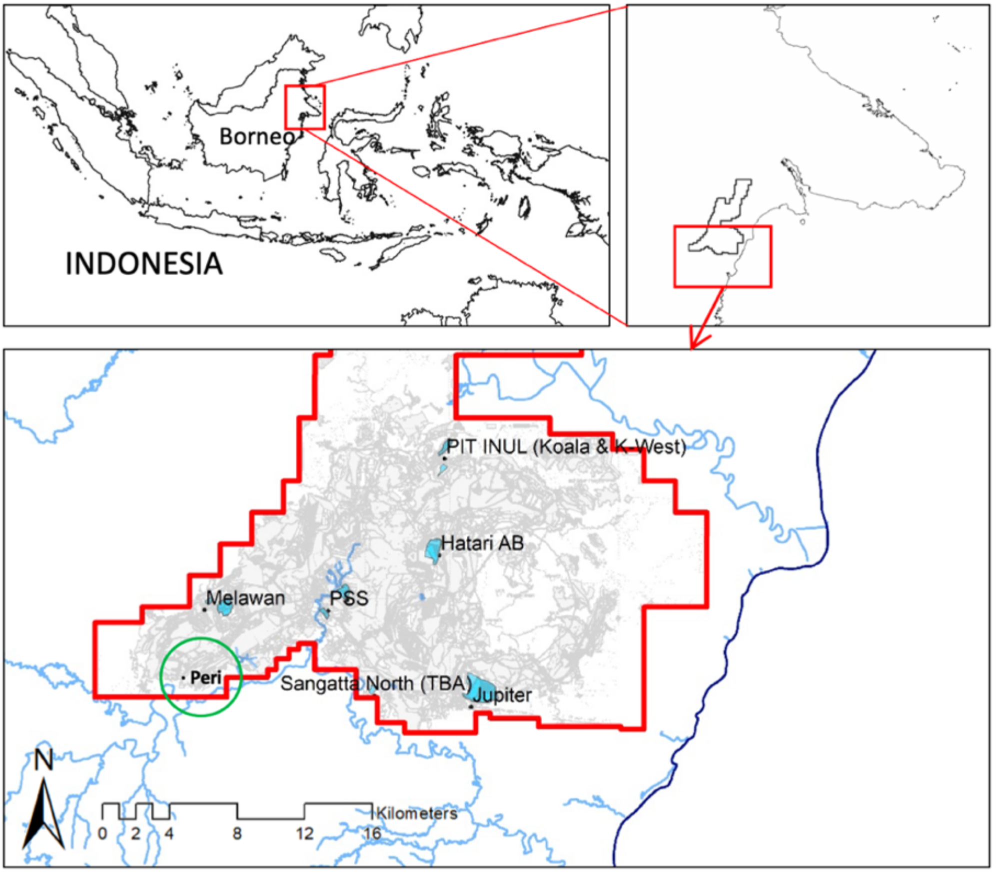

***Figure 1** Research Location*

The test was conducted in a long period of time, about 2 months, to determine the quality of leachate water over a long period of time. In this time period, tests were conducted in several cycles, namely daily, three-day, and weekly cycles. The daily cycle was carried out 26 times, three-day cycle was carried out 5 times, and weekly cycle was carried out once in location A. Test location A was mined, while tests were conducted twice in locations B and C. This pit wall leaching test activity was conducted in early December 2019 until the end of January 2020. The water used in the leaching process was distilled water. The distilled water used for watering was taken as much as 40 liters.

Rocks from each location were taken and tested in the laboratory, through static, mineralogy, and kinetic tests. Static and mineralogical tests were conducted in Mining Environment Laboratory and the Hydrogeology and Hydrogeochemical Laboratory owned by the Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology. Static test was the first step to characterize rocks. This test was designed to calculate the balance between acid-forming components (e.g., sulphide minerals) and acid consuming components, mainly carbonate minerals, in rock samples. Several tests conducted were pH, Total Sulphur, Acid Base Accounting (ABA), and Net Acid Generating (NAG) test. The test procedure was carried out according to the instructions on Amira International.

Mineralogy tests conducted were XRD (X-Ray Diffraction) and XRF (X-Ray Fluorescence) tests. XRD test was used to analyse the composition of phases or compounds in materials and to characterize

Figure 2 *Distribution of pit wall leaching test locations Distribution of pit wall leaching test locations*

crystals, while XRF test was generally used to analyse elements in minerals or rocks. Elemental analysis was conducted qualitatively and quantitatively. Qualitative analysis was conducted to analyse types of elements in the rock, while quantitative analysis was conducted to determine the concentration of elements in the rock.

Kinetic test in the laboratory was conducted using Free Column Drained Test (FDCLT) method, to investigate a long-term reaction between water and rock. Through this test, an overview of acid and wet generation of the reaction products was obtained. FDCLT was performed by placing rock samples in a Buchner funnel which was irradiated with the help of a light bulb, then watering was carried out in daily, three-day, and weekly cycles. The leachate water was accommodated in one container, which was then followed by a leachate water quality test.

Result and Discussion

Static Test

Result of the static test is shown in Table 1. Based on the result, sample A has a high pH value of 7.19, while samples B and C had 2.32 and 3.35. The value of Net Acid Generation (NAG) pH was 7.19 in sample A, 2.19 for sample B, and 3.08 for sample C. The value of Acid Neutral Capacity (NAC) was 23.61 for sample A, while samples B and C had no value. The sulfur content in each sample was 0.54 for sample A, 2.83 for sample B, and 1.70 for sample C. Total sulfur test results show that sample A was lower than samples B and C, namely 0.54% in sample A, 2.83% in sample B, and 1.70% in sample C. In sample A, Acidity Neutral Capacity (ANC) value was 23.61, while samples B and C had no value. The NAPP value indicates that sample A was negative with a value of -7.07, while samples B and C were positive with a value of 86.67 and 52.06, respectively.

With the geochemical characterization of rocks published by AMIRA that correlates the NAPP and NAG pH values, sample A was categorized as rock without potency to form acid mine drainage (NAF), while samples B and C were included in the category of rock forming acid mine drainage (PAF). Geochemical characterization shows that sample A was NAF as supported by other

Table 1 *Geochemical Characterization Results*

No.	Sample	pH Paste	Net Acid Generating (NAG)			Acid Base Accounting				Classification
			NAG pH	NAG pH 4.5	NAG pH 7	Total Sulphur	MPA	ANC	NAPP	
				(kg H2SO4/ton)		(%)	(kg H2SO4/ton)			
1	A	7.54	7.19	0	0	0.54	16.54	23.61	-7.07	NAF
2	B	2.32	2.19	76.44	122.5	2.83	86.67	0	86.67	PAF
3	C	3.35	3.08	13.23	21.854	1.70	52.06	0	52.06	PAF

parameters. The pH value in paste was high, NAG pH was also high, sulfur value was low, and ANC value affected acid neutralization independently. Samples B and C were classified as PAF, supported by low paste pH values, low NAG pH, high total sulfur and no ANC content.

Mineralogy Test

In XRD test result as shown in Figure 3, minerals in rock sample A were quartz (SiO_2), kaolinite ($Al_2Si_2O_9$), calcite ($CaCO_3$), periclase (MgO), montmorillonite [(Na,Ca)0.33(Al,Mg) 2(Si_4O_{10})$(OH)_2 \cdot nH_2O$], and siderite ($FeCO_3$). Minerals in rock sample B were quartz (SiO_2), kaolinite ($Al_2Si_2O_9$), jarosite [$KFe_3(SO_4)_2(OH)_6$], pyrite (FeS_2) and magnetite (Fe_3O_4). Minerals in rock sample C were quartz (SiO_2), kaolinite ($Al_2Si_2O_9$), magnetite (Fe_3O_4), pyrite (FeS_2), and jarosite [$KFe_3(SO_4)_2(OH)_6$]. Based on the results of geochemical characterization, sample A had calcite and montmorillonite minerals which tended to neutralize acids, because capable of absorbing hydrogen content in acid mine drainage (Gautama, 2014), so sample A is classified as rock without potency to form acid mine drainage. Samples B and C were classified as Potential Acid Forming (PAF) rocks, due to the presence of pyrite minerals as the main sulphide mineral (Castendyk, Eary and Balistrieri, 2015) (Eary, 1999) and jarosite minerals as secondary minerals from the weathering of sulphide minerals (Gautama, 2014).

The result of XRF in Table 2 shows that mineral elements in three samples were Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Fe, Cu, Zn, Rb, Sr, and Zr. Sample C had As elements. Sample A had 3 dominant elements, namely Si (64.1%), Al (20.5%), and Fe (8.57%). Dominant elements in sample B were Si (52.9%), Al (20.9), and Cu (8.22%). Sample C had dominant elements, namely Si (72.8%), Al (15.6%), and Fe (6.23%). Content of elements in each sample is shown in Table 2.

Leachate Water Quality

Sample A was a rock with a predominance of clay. Based on the result of field test, pH value was in the range of 7.11-7.90 for daily cycle, in the range of 7.61-8.02, for three-day cycle, while weekly cycle only had 1 value because it has only been tested once with a pH value of 7.9. Sample B was rock containing carbon. Based on the result of pit wall leaching test, pH value was in the range of 1.99-2.77 for daily cycle, in the range of 2.07-2.5 for three-day cycle, and in the range of 2.07-2.5 for weekly cycle. Sample C was a rock dominated by sandstone. Based on the result of pit wall leaching test, pH value was in the range of 3.10-3.96 for daily cycle, in the range of 2.89-4.09 for three-day cycle, and in the range of

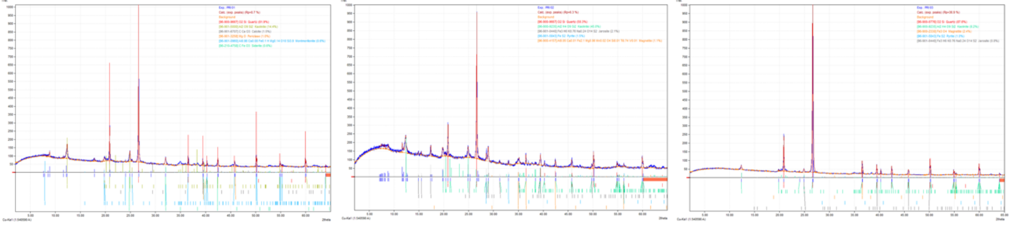

Figure 3 *Hasil Uji XRD*

Table 2 XRD and XRF test results

Sample.	XRD	XRF
A	Quartz, kaolinite, calcite, periclase, montmorillonite, siderite	Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Fe, Cu, Zn, Rb, Sr, Zr
B	Quartz, kaolinite, jarosite, pyrite, magnetite	Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Fe, Cu, Zn, Rb, Sr, Zr
C	Quartz, kaolinite, jarosite, pyrite, magnetite.	Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Fe, Cu, Zn, As, Rb, Sr, Zr

3.26-3.46 for weekly cycle. Sample B shows the similarity of pH value in the result of kinetic test using rock samples from veryta blocks from different pits, where the result of kinetic test on a weekly cycle was in the range of 1.5 – 2.5 (Abfertiawan *et al.*, 2020).

Based on Figure 4, it can be seen that the ORP value in the pit wall leaching activity shows that the ORP value of sample A is negative which is in the range of -100 to 0 mV. Samples B and C have ORP values in the range of 150 to 300 mV and have positive values. It can be seen in the figure which shows that along with the high pH value, the ORP value will decrease, on the contrary if the pH value is low, the ORP value will be high.

For value of Total Dissolved Solids (TDS) from the result of leachate test and the pit wall leaching test, each sample is shown in Figure 4. Sample A had a TDS value range of 124 - 595 ppm in the daily cycle, in the range of 135 – 309.7 in three-day cycle, and 1 measurement with a value of 247.9 ppm in weekly cycle. Sample B had a higher TDS value than other two samples, with a value range of 2,853 – 4,388 ppm for daily cycle, in the range of 960 – 4,533 ppm for three-day cycle, and in the range of 5,126 – 5,428 ppm for weekly cycle. Sample C had a TDS value in the range of 53 - 816 ppm for daily cycle, in the range of 126 - 348 ppm for three-day cycle, and in the range of 558 – 1,088 ppm for weekly cycle. TDS value in sample B was higher than that in samples A and C. High content of TDS in sample B was due to the high sulfate content in leachate.

Based on the classification of pit lake types to be formed and leachate in the field and laboratory, there were two pit lake types (Figure 5), namely Acidic - High TDS and Circumneutral - Low TDS types (Eary, 1999). Based on classification, sample in location A was included in the Circumneutral TDS and sample B was in Acid-high TDS zone, and sample C was in Acid-low TDS zone.

Chemical Content Test

Based on the results of metal test on leachate, value of Fe in sample B was the highest, compared with other samples. High Fe content was due to a low pH value. Metals that have been environmental quality standards issued by Indonesian government are Fe and Mn. Based on the results of metal test in Table 3, there is a tendency for high Fe values to exceed the quality standard limit of 6 mg/L, while Fe in leachate water was greater than the quality standard, particularly in sample B in the range of 104 - 836 mg/L. Mn metal in leachate of all samples was still below the specified quality standard of 4mg/L.

The same applied to SO4 content, where sample B was the highest, compared with other two samples. Besides these two metals, other metals (e.g., Al, Mn, and Mg) were dominant in sample B. High values of Fe and SO4 in sample B were due to the presence of pyrite content in sample B.

Conclusion

The geochemical characterization of rock on the rock wall was then verified by laboratory test as a reference for the industry to predict water quality to be formed when a former mining pit will be used as a pit lake. The results based on static test indicate that locations B and C are rocks categorized into Potential Acid Forming (PAF) as characterized by the presence of sulfide minerals, namely pyrite, in these rocks. Meanwhile, for sample A, rocks are categorized into Non Acid Forming rocks (NAF). Kinetic test, pH value in particular, shows that there was a similar trend between values in pit wall leaching and kinetic tests in the laboratory. Based on the relation between pH and TDS, sample A was in the Circumneutral - Low TDS zone, while samples B and C were in the acidic - High TDS zone. Metal content (Fe and Mn in particular) as the requirements for environmental quality

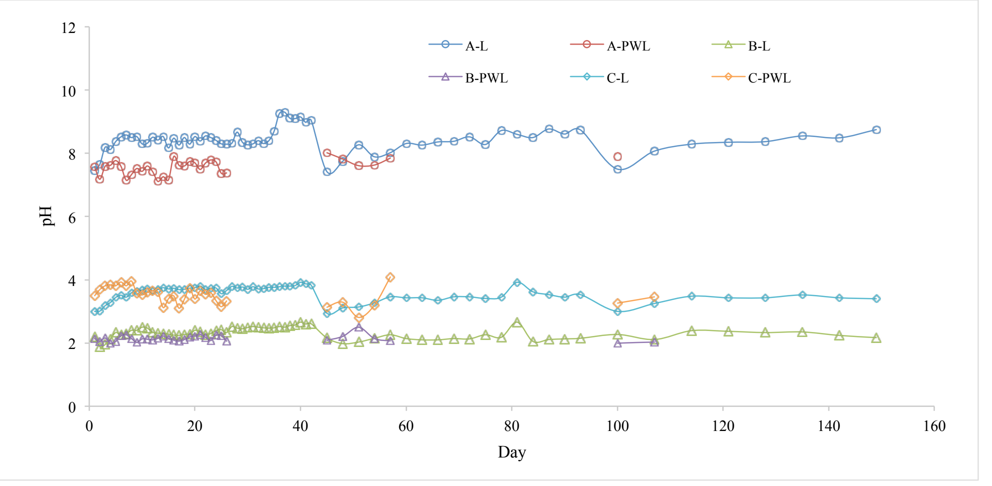

***Figure 4** pH value of leachate water*

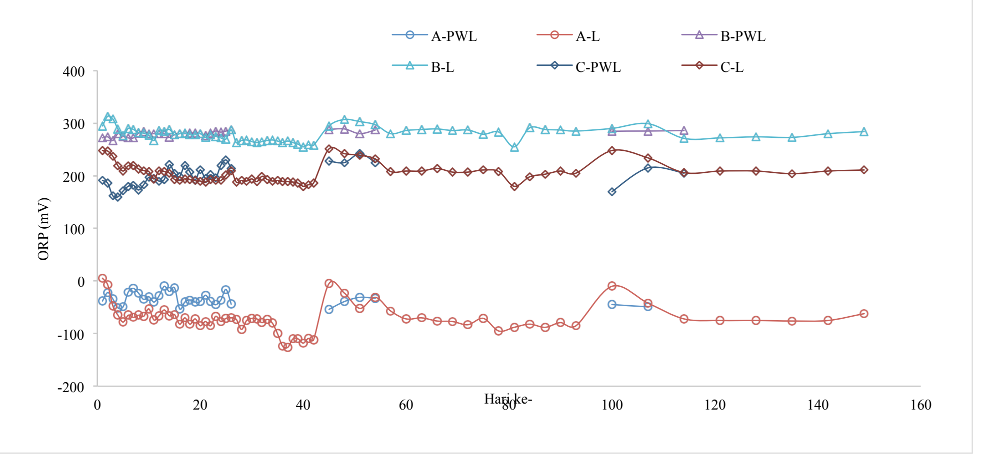

***Figure 4** ORP value of leachate water*

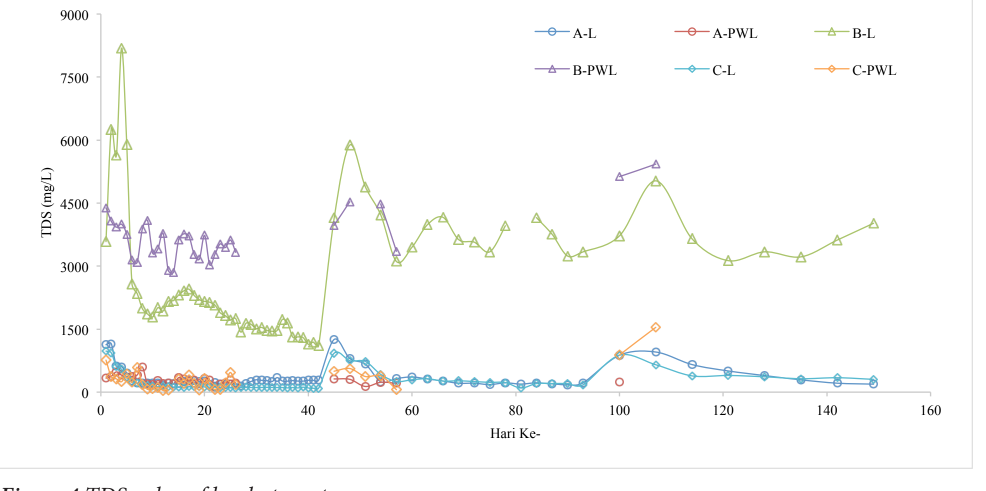

***Figure 4** TDS value of leachate water*

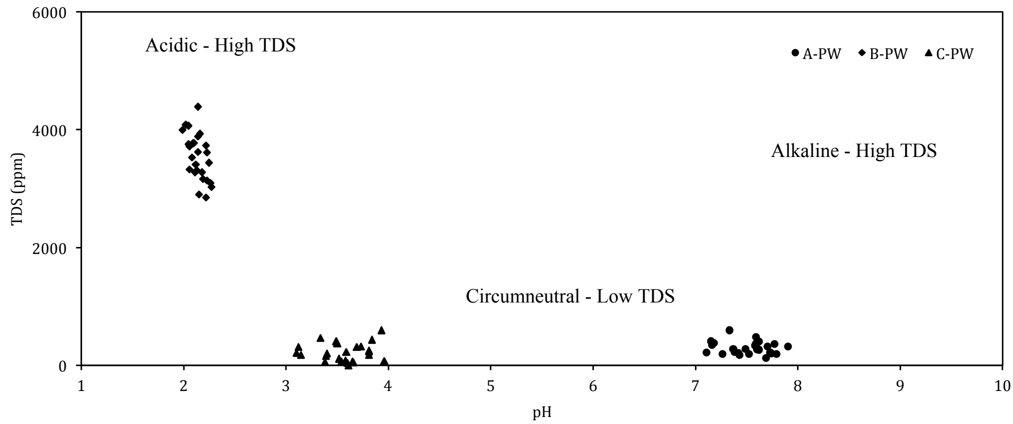

Figure 5 *Category of Pit Lake from Leachate Result*

standards in Indonesia, got the highest value in samples B and A.

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Table 3 *Chemical content of leachate*

Parameter	Day 1 (Beginning)			Day 13 (Intermediate)			Day 26 (End)			Day 35 (three-day)			Day 55 (Weekly)	
Na (mg/L)	14.6	2.58	3.92	10.7	0.58	0	8.96	0.76	0.55	5.22	0	0	0.84	0.61
Ca (mg/L)	45.9	45.9	214	28	61.1	2.69	27	71.8	23.7	22.9	21.7	5.62	209	28.2
K (mg/L)	18.8	0	1.2	12.7	0	0	13.8	0	0	11.4	0	0	0	0.59
Mg (mg/L)	52.6	345	137.0	43	124	1.1	41.7	159	8.27	37	33.5	6.18	286	11.2
Al (mg/L)	0.505	62.2	5.7	0.847	51.2	0.112	0.48	292	2.7	0.75	50.7	12.1	557	3.08
Fe (mg/L)	14.3	817	16.9	0.71	408	0.89	42.2	348	1.84	71.9	104	36.4	836	4.02
Mn (mg/L)	1.53	5.4	3.23	1.39	6.16	0	0.944	5.52	1.38	1.46	3.14	1.21	3.74	1.57
Cr (mg/L)	0	0	0	0	0.0841	0	0	0.082	0	0	0.0415	0	0.0553	0
Cd (mg/L)	0	0.006	0.003	0.0025	0	0	0	0.003	0	0	0	0	0.0053	0
SO_4 (mg/L)	332	4000	1100	210	2270	19	183	3840	121	93	879	264	3620	167
NH_3-N (mg/L)	0	0.05	0.2	0.34	0	0	0.21	0.66	0.15	0.55	0.67	0.17	0.41	0.14
F^- (mg/L)	0.91	0.27	1.18	0.88	0.87	0.22	0.63	0.74	0.7	0.74	1.28	0.91	0.16	0.79
I^- (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cl^- (mg/L)	4.4	0	3.3	1.6	0	0	8.96	9.8	0	0	0	0	0	0
NO^{3-} (mg/L)	0	1.28	0	0	0.911	0.015	0	0.846	0	0	0.015	0	1.6	0.006

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