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Characterization of the Pit Lake Area for Sustainable Management at a Coal Mine in Central Kalimantan, Indonesia

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Abstract: A pit lake, formed at the end of mining activities, can potentially be sustainably utilized. Several mines in Indonesia have reached the end of post-mining, and some have been abandoned as voids that eventually become lakes. Pit lake planning needs to be conducted to ensure these lakes are useful and sustainable. One of the former mining areas that has become a pit lake is located in Central Kalimantan. The dimensions of the pit lake are 2,300 m long, 620 m wide, and approximately 68 m deep. The amount of water in the pit lake is estimated to be approximately 37.5 million m^3. This research was conducted to determine the potential use of the pit lake by characterizing the factors affecting its sustainable use. Observations were carried out to comprehensively understand the characteristics of the pit lake area. Field measurements were carried out to assess water quality, while rock samples were taken to analyze their geochemistry. Measurements in the field indicated that the lake water pH was in the range of 5 to 6. Meanwhile, the area around the pit lake has several open areas where revegetation has failed, resulting in rock exposure around the pit lake area. Geochemical tests on 23 samples from around the pit lake area showed that 15 samples had pH values below 6. Mineralogical tests on 4 samples indicated the presence of secondary minerals generating acid mine drainage, such as jarosite. Based on the obtained results, efforts must continue for the long-term use of the pit lake, including the closure of open areas and water treatment, so that the water can be used for operational needs in the field.

1. Introduction

A pit lake is formed in mining pits that has been exhausted and is then allowed to fill with water, either directly from rainwater/surface water and groundwater inflows [1]. Factors affecting pit lake formation include geometry, hydrological and hydrological conditions [2], and the surrounding climate. Pit lakes in several areas have been used for cultivation, tourism, water source, etc. [3]. A pit lake with suitable water quality can typically be utilized, without any negative effect on the surrounding environment. However, it is quite common that water quality issues can develop due to the formation of acid mine drainage due to the reaction between sulfide minerals and oxygen in the presence of water [4]. According to the regulatory system in Indonesia, the water in coal mines can be used as public waters if it has a pH between 6 and 9 [5].

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One of the coal mining companies located in Central Kalimantan, Indonesia has been carrying out mining operations, where one of the former mining pits has turned into a pit lake. In terms of geometry, the pit lake size is 2,300 m long, 620 m wide, and 68 m deep with an area of approximately 132 ha. As pit lakes filling has continued, the resultant pit lake has developed a water quality between pH 5 and 6, which failed to meet the relevant environmental standards (pH 6 – 9). The development of the pit lake at this site occurred very quickly, in around two years. The main water source is from surface water, as the area is generally swampy with a natural water quality condition between pH 4 and 5. Since the water source from which it formed had a low pH value, this contributed to low water quality in the pit lake. Efforts that have been made to attain good water quality include the prevention of surface water flows from penetrating the wetland, reclamation of the rain catchment areas, and treatment of the water coming out of the pit lake.

Based on the description above, the pit lake in this mining area has the potential for sustainable use. This research was conducted to characterize the pit lake area particularly in terms of water quality, geochemistry, and mineralogy of rocks and vegetation cover around the mining area. Characterization of the factors affecting water quality provides recommendations for an effective pit lake management, for realizing sustainable use.

2. Method

2.1. Sampling

The terrain immediately surrounding the pit lake has open areas that are not covered by vegetation. Sampling was carried out these areas to determine the rock's geochemistry. A total of 23 rock samples were taken from pit walls and categorized into three zones, namely (1) low walls, marked in green; (2) high walls, marked in blue; and (3) side walls, marked in yellow (**Figure 1**). Apart from the rock samples, water samples were collected from the pit lake at several points, and these are considered to represent the entire pit lake area. Water sampling in the pit lake was carried out using a random sampling method.

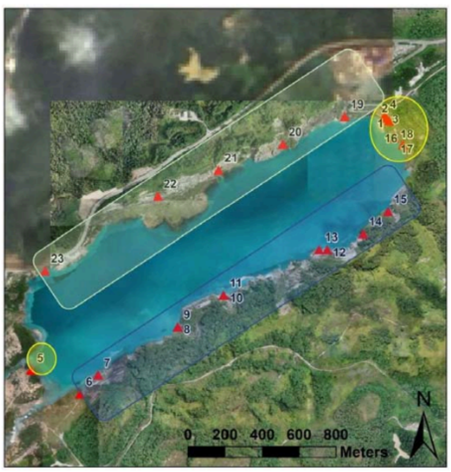

Figure 1. Map of the area where rock samples were taken

2.2. Laboratory Testing
Rock samples obtained in the field were then subjected to sample preparation to meet the requirements of each test. Static tests were carried out based on the Indonesian National Standard (SNI) 6957:2021 and AMIRA 2002 [6]. These tests included paste pH, total sulfur, NAG (net acid generating) acid formation test, ANC (acid neutralizing capacity) acid neutralization test. These tests were conducted to achieve an initial understanding regarding the geochemical characterization of rocks, specifically whether they were potentially acid forming (PAF) or non-acid forming (NAF) [7]. Tests were carried out in the Tekmira Laboratory, Bandung, Indonesia and the Coal Quality Laboratory, Mining Dept., Trisakti University. XRD was also carried out to identify the mineral content in rocks, mainly to confirm the presence of sulfide minerals in the rocks exposed in the pit wall area, and the better evaluate the cause of the low pH water in the pit lake.

3. Results and Discussion

3.1. Water Quality and Vegetation
The water quality measurements taken in the pit lake recorded pH values in the range 5 to 6. These results are not in accordance with the quality standards as set by the Government of the Republic of Indonesia namely a pH value in the range of 6 to 9. The water quality that develops in pit lake needs to be will affect its future long-term use, hence careful management of the terrain around a pit lake needs to be carried out. A low pH value in the pit lake can be caused by several factors, but principally includes the exposure of rock areas on the pit walls. The exposed opening is caused by a failure to grow vegetation and also by landslide on the pit walls which leads to new rock exposure. These exposes result in the introduction of low pH water to the pit lake [8].

Water quality measurements conducted in surrounding pools and ponds present pH value was between 5 – 6, indicating source of acid mine drainage from the pit wall area which have not been adequately covered by vegetation. The primary factor affecting water quality in pit lake is the presence of vegetation around the pit lake area (**Figure 2**). Better more developed vegetation in the area around the pit lake will provide for a substantial water quality improvement [9].

3.2. Static Testwork
The static testwork results presented in **Table 1** indicated 9 samples with a paste pH value <5.0 LP1, LP2, LP 6, LP 14, LP 17, LP 19, LP 20, LP 22, LP 23. In addition, 7 of 9 samples had a NAG pH value < 5.0 and a large total sulfur percentage value. These findings indicate that some of these samples can be categorized as PAF. In the ANC test results, 12 samples presented low ANC values including negative values, while the highest ANC value in sample LP 16 was 1,196.58 kg H_2SO_4/t. This finding showed that this sample had a high capacity to neutralize acid, while a sample, namely LP 11, had the lowest ANC value of -32.83 kg H_2SO_4/t. In other words, these samples had a low neutralization capacity. Based on the results of the static testwork and specifically the interpretation of the rock's geochemical characterization, seven samples were categorized as PAF or having a pH value (net acid generating) NAG < 4.5. Samples LP 1, LP 15, LP 19 had (net acid producing potential) NAPP value > 0. Referring to the Indonesian National Standard 6597:2011, these three samples were classified as low PAF rock types because the NAG pH value in these four samples was <4.5, in which the NAG value at pH 4.5 was less than 5 kg H_2SO_4/ ton and NAPP value < 10 kg. The other four samples (LP 17, LP 20, LP 22, LP 23) were classified as high PAF rock types because of having NAG pH value at <4.5, the paste pH value at < 4.5, the NAG pH value at 4.5 ≤ 5 H_2SO_4/ton, and NAPP value at ≤ 10 kg H_2SO_4/ton. Meanwhile, 16 other samples had NAG pH at > 4.5 and NAPP value at < 0. Thus, these three samples did not have any real potential to form acid nor were categorized into the NAF rock type.

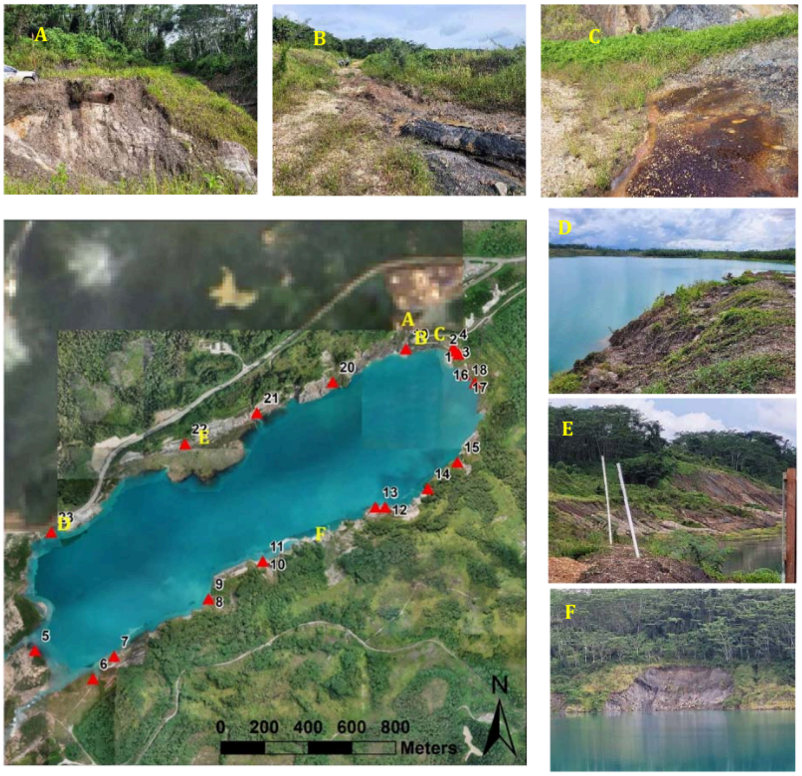

Figure 2. Condition of vegetation and openings in the area around the pit lake

3.3. Mineralogy Testwork

The XRD testwork that was conducted on sample LP6 is shows the minerals found in this sample were quartz (SiO2), illite $(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)$, and kaolinite $(Al_2Si_2O_5(OH)_4)$. Based on the mineral composition (Table 2), illite dominated the rock at a percentage of 63.08%, followed by kaolinite at 21.08% and quartz at 15.12%. The XRD testwork conducted on sample LP12 indicate showed the result that minerals found in this sample were quartz, illite, kaolinite, and feldspar. Based on the mineral composition as shown in Table 2, illite dominated the rock at a percentage of 66.52%, followed by quartz at 26.06%, kaolinite at 6.51%, and feldspar $(KAlSi_3O_8)$ at 0.91%. The XRD testwork conducted on sample LP17 is presented in Figure 3c and illustrates that the result minerals found in this sample were quartz, illite, kaolinite, and feldspar.

Table 1. Static Test Result

No.	Sample Code	Paste pH	pH NAG	NAG*		ANC	S Total (%)	MPA*	NAPP*
				pH 4,5	pH 7,0				
1	LP 1	3.99	4.09	0.3	7.6	-0.3	0.09	2.80	3.10
2	LP 2	4.8	5.5	<0.01	8.82	-18.13	0.03	0.90	19.03
3	LP 3	5.17	3.71	2.2	9	27.50	0.55	16.80	-10.70
4	LP 4	7.71	7.72	<0.01	<0.01	36.4	0.1	3.10	-33.30
5	LP 5	5.3	5.4	<0.01	1.96	-4.9	0.11	3.37	8.27
6	LP 6	4.5	4.7	4.7	2.93	-24.01	0.05	1.53	25.54
7	LP 7	8.03	7.81	7.81	<0.01	17.3	0.092	2.8	-14.5
8	LP 8	8	5.4	<0.01	8.82	-15.19	0.45	13.77	28.96
9	LP 9	7.51	4.49	0.1	9	27.4	0.21	6.4	-21
10	LP 10	5.41	5.03	<0.01	6.4	1	0.071	2.2	1.2
11	LP 11	5.5	5.5	<0.01	7.84	-32.83	0.08	2.45	35.28
12	LP 12	6.4	5.9	<0.01	1.96	-18.13	0.02	0.61	18.74
13	LP 13	5.88	4.65	<0.01	8.1	0.5	0.067	2.1	1.6
14	LP 14	4.8	5.2	<0.01	8.81	-4.9	0.16	4.96	9.86
15	LP 15	5.22	4.44	0.1	9.7	-1.3	0.067	2.1	3.3
16	LP 16	8.1	7.2	<0.01	<0.01	1,196.58	0.13	4.08	-192.50
17	LP 17	3.3	2.8	19.59	44.08	-29.89	0.05	1.53	31.42
18	LP 18	6.2	5.2	<0.01	11.76	6.86	0.11	3.37	-3.49
19	LP 19	4.74	4.06	0.4	7.5	0.2	0.096	2.9	2.8
20	LP 20	2.2	1.82	124.5	178.3	-18.5	2.620	80.2	98.7
21	LP 21	6.24	7.67	<0.01	<0.01	78.5	0.54	16.5	-62
22	LP 22	4.38	2.12	54.3	86.3	1.9	0.94	28.9	26.9
23	LP 23	4.09	2.69	15.9	31.3	-0.8	0.47	14.4	15.2

*Note: *Units in Kg H_2SO_4/ton; NAG (Net Acid Generation); ANC (Acid Neutralizing Capacity); S (sulphur); MPA (Maximum Potential Acidity); NAPP (Net Acid Producing Potential)*

Based on the XRD test results obtained for different minerals found in four samples labeled LP6, LP12, LP17, and LP18, the minerals are identified by their chemical composition: Quartz (SiO_2): LP6: 15.12%; LP12: 26.06%; LP17: 31.94%; LP18: 23.30%. Illite ($(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$: LP6: 63.08%; LP12: 66.52%; LP17: 37.83%; LP18: 59.72%. Kaolinite ($Al_2Si_2O_5(OH)_4$): LP6: 21.80%; LP12: 6.51%; LP17: 27.28%; LP18: 15.38%. Feldspar (KAlSi3O8): LP12: 0.91%; LP18: 1.60%. Jarosite ($KFe_3(SO_4)_2(OH)_6$): LP17: 2.95%. All rock sample, subjected to mineralogical testing had no major acid-forming minerals or sulfide minerals in general. With the presence of secondary acid-generating minerals, namely jarosite on sample LP17 will have an influence on pit lake water quality, especially related to heavy metals [10].

3.4. Potential Use of Pit Lake

Potential Use of the Pit Lake Based on this characterization, the pit lake has a potential for the future use. The lake could be used as aquaculture, for nurturing and breeding freshwater fish, because the area around the lake has a large river for freshwater fish breeding. Another potential use is as a water source for communities around the mine [11]. Also, the pit lake can be developed into a tourist attraction for the local community. Since the pit lake is located in the Central Kalimantan region, without any access to marine water tourism, the pit lake could become a tourist attraction.

4. Conclusion

The water quality test in the field showed a low pH value, with a range of 5 - 6, which needs to be attended to when conducting water treatment in the future. Based on the tests that have been carried out, seven of the 23 samples (LP 1, LP 15, LP 17, LP 19, LP 20, LP 22, LP 23) were categorized as PAF because of a NAG pH <4.5 and a small ANC value at <2, thus having a little potencyto neutralize acid. Three of seven samples were classified as low PAF, while the other four were classified as high PAF. Three samples were categorized as NAF. Mineralogical tests carried out on several rock samples showed that the rocks contained secondary minerals namely jarosite that formed AMD. The pit lake has the potential to be used in the future, for various purposes, including fish cultivation and tourist area, because of being located in Central Kalimantan region.

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