Geochemical Characterization of Pit Wall Rocks: A Preliminary Step in Predicting the Water Quality of Pit Lake

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Geochemical Characterization of Pit Wall Rocks: A Preliminary Step in Predicting the Water Quality of Pit Lake

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Abstract: The quality of pit lake water during development and final condition is affected by various factors, including geochemical characterization of materials of a pit wall, which may consist of in-situ and backfilling materials. This research aims to obtain a geochemical characterization of pit wall materials using 3 main laboratory tests and analysis, namely static test, mineralogical and elemental composition analysis, and kinetic test using free draining column leach test. Static test results show that 5 of 6 samples exhibit low paste pH and NAG pH. Pyrite is found in four samples and is responsible for acid mine drainage production. Some samples contain acid-consuming carbonates and oxides such as calcite and periclase. Four samples exhibit leachates' pH values lower than 3,00, mostly during all cycles. Alongside the lithostratigraphic distribution of pit wall rocks, these results imply a potential occurrence of acid mine drainage that will become a critical issue for water quality development and final condition in pit lake formation. Therefore, these results become essential feedback for the stakeholders to plan and implement acid mine drainage management to minimize the adverse impact of acid mine drainage in pit lakes. Immediate understanding of the geochemical characteristics of leachates from pit wall rock, which control the overall mine water quality.

1. Introduction

Open-pit mining method currently dominates mining activities in the world. Coal and mineral mining activities on large-scale mining will leave behind openings that will become ex-mining holes. Lakes will be formed when water fills such openings, commonly known as ex-mining lakes or pit lakes [1] [2]. Indonesian mining regulations allow pit lakes as one of the mine-closure programs, known as reclamation in other forms, considering complete backfilling (in-pit dump) is not possible for several conditions [3]. Pit lakes resulting from coal mines require immediate planning and management measures to comply with the regulatory standards and planned final utilizations, including pit lakes' expected water quality level.

The formation of acid water drainage aggravates the water quality from coal mining pits [4], which is the result of a reaction among sulfide minerals, oxygen, and water [5] [6], especially from exposed PAF materials on the pit wall. Acid mine drainage formation may continue after mine closure as pit lakes develop. One of the methods applicable to reduce or prevent the reaction between water and PAF materials on the pit wall is to cover the pit wall. It is done by backfilling the bottom of the pit with PAF materials and then covering it with NAF (Non-acid Forming) materials. If the pit wall is dominated by NAF rock, using PAF material.

This research aims to determine the character of overburden materials in the pit and the character of rocks exposed on the pit wall through the employment of different laboratory methods, including static tests, mineralogical dan elemental composition analysis, and kinetic tests. Furthermore, the geochemical characteristics will serve as a preliminary stage and input in predicting the quality of acid mine drainage generated from the reaction of runoff water with overburden materials and exposed rocks during the development and final stages of the pit condition.

2. Method

2.1. Sampling

A mine pit is a coal mine area that is half water filled with the following dimensions: length, width, and depth are approximately 3500m, 1000m, and 450m, respectively. In the western and eastern parts of the mine pit, overburden materials dumped from the adjacent pits cover the material in the pit (in-situ materials). Revegetation is also carried out and finalized in the eastern part of the pit, while reclamation activity is still in progress in the western part of the pit. Sampling was not carried out on the northern and southern walls because the northern area has completed revegetation while the southern area is submerged in water. Six samples were taken randomly using the grab-sampling method [7] [8]. The samples represent all materials comprising the mine pit, in-situ materials, and materials from the adjacent pits. Four of the six samples were taken from different dumping areas, namely IPD-01 and IPD-02 from the active reclamation area (western part of the mine pit); FB-01 and FB-02 from the reclaimed area (eastern part of the mine pit). Two other samples were collected from the exposed in-situ materials on the pit wall/slope, labeled as PW-01 and PW-02. The sampling location map and documentation are available in the following figure (**Figure 1**).

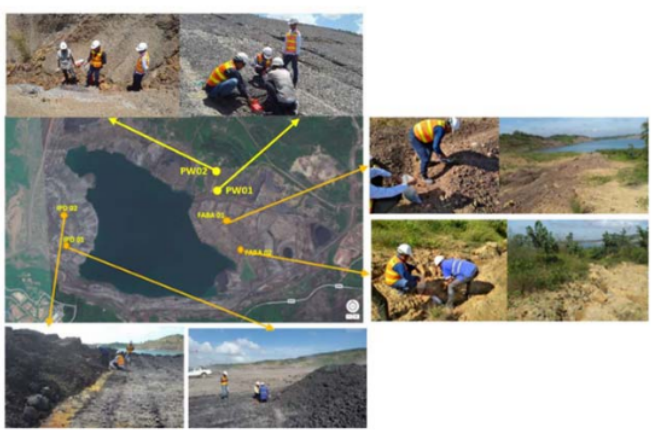

Figure 1. Sampling site

2.2. Laboratory Testing

The samples were prepared by drying, splitting, and comminution (crushing, grinding, and milling) in order to meet the required weight and size for the subsequent testing and analysis, which are as follows:

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1. Mineralogical and elemental composition test is conducted to identify and quantify the samples' major minerals and elements. X-Ray diffraction (XRD) test were carried out at the Hydrogeology and Hydrogeochemical Laboratory of Institut Teknologi Bandung (ITB). XRD test was conducted using Rigaku *SmartLab X-ray Diffraction* System (XRD) [9].
2. Static Test: Static tests were conducted based on AMIRA 2002 and Indonesian National Standard (SNI) 6597:2011. The protocol includes; (i) paste pH to assess the immediate balance between acidity and alkalinity of the samples to show the natural condition of samples; (ii) total sulfur to identify all sulfur contents in the samples through high-temperature combustion with excess oxygen. Sulfur oxide produced from combustion was then analyzed using an IR detector. In addition, (iii) Acid Neutralizing Capacity Test, to calculate the rock's ability to neutralize acid, and (iv) Net Acid Formation Test, PAN/Net Acid Generating, NAG, was conducted to obtain a net amount of acid produced from the rock samples [10].
3. A kinetic test was conducted to investigate the kinetic reaction of acid formation in the samples by simulating rock oxidation reactions. In addition, a kinetic test was also conducted to predict the water quality of the samples when acid-producing, buffering, and neutralization reactions took place in the long run. This test was carried out using Free Draining Column Leach Test (FDCLT) method [11].
4. On the other hand, the deionization process is only removing dissolved ions. Leachates were collected into an Erlenmeyer flask and measured for physio-chemical parameters, including pH value. A wet cycle is repeated daily for the daily cycle, a 3-day cycle for every other 3 days, etc. In this study, the kinetic test was conducted for 156 days with a daily cycle of 28 tests, a 3-day cycle of 10 tests, a weekly cycle of 8 tests, and a 2-week cycle of 3 tests.

3. Results and Discussion

3.1. Static Test

Static test results **(Table 1)** reveal that 5 samples exhibit low paste pH and NAG pH (sample IPD-01, IPD-02, FB-02, PW-01, and PW-02). Four of the five samples have high TS value and no ANC value, yielding high NAPP value varies from 12,55 - 39.81kg H_2SO_4/ton rock. Only 1 sample (FB-01) shows acid-neutralizing capacity/ANC of 29.83kg H_2SO_4/ton rock. The samples with ANC are expected to have neutralization capability.

Table 1. Result of Static Test

No	Code	Paste pH	ANC*	NAG pH	NAG*		Tot. Sulfur (%)	MPA*	NAPP*	CLASS
					pH 4.5	pH 7				
1.	IPD-01	3.53	0	1.86	64.92	93.10	0.41	12.55	12.55	PAF
2.	IPD-02	3.16	0	2.50	13.57	21.24	1.10	33.68	33.68	PAF
3.	FB-01	7.11	29.83	6.90	0	0.24	2.11	64.61	34.78	UC
4.	FB-02	3.90	0	3.25	3.97	10.67	0.16	4.90	4.90	PAF
5.	PW-01	2.45	0	2.71	29.46	47.01	1.32	39.81	39.81	PAF
6.	PW-02	2.25	0	2.88	13.00	20.85	0.84	25.39	25.39	PAF

Note: *unit in kg H_2SO_4/t, ANC: acid-neutral capacity; NAG: Net Acid Generation; MPA: Maximum Potentially Acidity; NAPP: net acid production potential; Class: classification

Based on the static test results, the geochemical classification or screening criteria use NAG pH value, and the NAPP value is based on AMIRA [12]. The 5 samples are proven to fall in the classification of potentially acid forming (PAF) with NAG pH value less than 4.50 and NAPP value higher than 0kg H_2SO_4/ton rock, i.e., samples IPD-01; IPD-02; FB-02; PW-01; and PW-02. One sample (FB-01) falls on the uncertain classification with NAG pH value of 7.11 and NAPP value of 34.78 kg H_2SO_4/ton rock. The results of the kinetic test, the mineralogical and elemental composition will be further considered to classify and identify the potentials of acid mine drainage production, buffering, and neutralization for each sample.

3.2. Mineralogical and Elemental Composition

XRD test results show that pyrite is found in four samples, i.e., IPD-01, IPD-02, FB-01, and PW-01, and is responsible for acid mine drainage production (**Figure 2**). Higher sulfur-iron content showed in XRF results also confirms these minerals as potentially acid-forming materials. In addition, some samples contain acid-consuming carbonates and oxides, such as calcite (in samples IPD-02 and FB-01) and periclase (in samples IPD-02, FB-01, and FB-02).

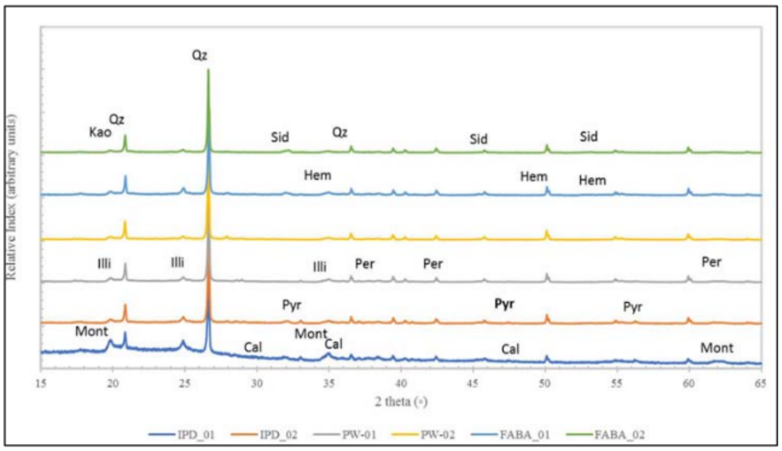

Figure 2. Mineralogy on rock samples

3.3. Kinetic Test

Leachates' pH value taken from a kinetic test using the free draining column leach test method shows variability in pH values across samples and temporal sampling from different cycles. The graphic depicts pH value over time is shown in the following picture (**Figure 3**). Leachates from all samples show high-variability of pH value on daily cycle / first 30 days due to a phenomenon called initial flushing condition. During this phase, all pre-existing secondary minerals and products from acid production, acid buffering, and neutralization are leached and produce more variable pH and TDS values. On 3 daily – weekly cycles, pH variation is diminished, except for FB-01 samples. Meanwhile, the variation in the pH value of leachates is negligible in the biweekly cycle. After an extended kinetic test (>100 days), acid-producing, buffering, and neutralizing reaction rates are more stable than initial cycles, as indicated by lower variation of pH values.

Four samples mostly exhibit leachates' pH values lower than 3.00 during all cycles, i.e., IPD-01, IPD-02, PW-01, and PW-02. IPD-01 pH values range from 2.08 to 4.10; IPD-02 pH values range from 2.21 to 3.87. Meanwhile, PW-01 pH and PW-02 pH values range from 1.95 to 3.48 and 2.01 to 3.52, respectively. Therefore, these samples fall under the classification of potentially acid-forming (PAF) samples with NAPP values varying from 12.55 – 39.81kg H_2SO_4/ton and no ANC value.

Two samples, namely FB-01 and FB-02, are producing less-acid leachates with overall pH values over 4,00. FB-01 yields circumneutral-alkali leachates with pH value ranging from 5.36 to 7,49, in the other hand, FB-02 produce leachate with limited alkalinity pf pH value ranging from 3.87 to 5.89. FB-01 sample yields higher pH value leachates due to high ANC value (29.83 kg H2SO4/ton). There is also the presence of neutralizing minerals such as calcite and periclase. At the same time, FB-02 has neither ANC nor neutralizing minerals, with a lower NAPP value of 4.90 kg H_2SO_4 and paste pH and NAG pH values of 3.90 and 3.25, respectively. Therefore, it yields a higher pH value than the PAF mentioned above samples. Thus FB-01 falls in the classification of non-acid forming (PAF) materials, and FB-2 falls in the classification of potential acid-forming materials – low capacity (PAF-LC) due to pH leachates from the kinetic test is less acid / more than 4,00.

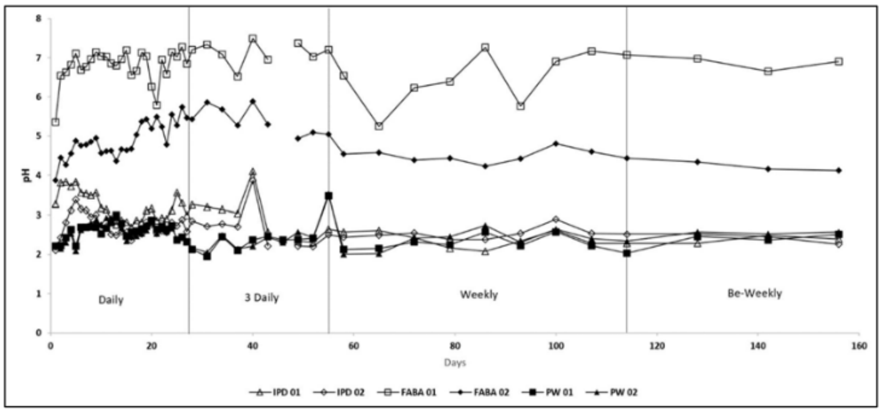

Figure 3. Kinetic test results

3.4. Overall Geochemical Characteristics of Samples

Geochemical characterization, including static test; mineralogical and elemental composition analysis; and kinetic test using free-draining column leach test, offers a more comprehensive and complete picture of acid-producing and acid-neutralizing characteristics in the long run. All samples are considered representative of the rocks in the area around the pit lake. Most samples (4 out of 6 samples) are characterized as PAF material, while 2 others are characterized as PAF-low capacity and non-acid forming materials.

Alongside the lithostratigraphic distribution of pit wall rocks, these results imply that there was a potential occurrence of acid mine drainage that would become a critical issue for water quality development and final condition in pit lake formation. Therefore, these results become essential feedback for the stakeholders to plan and implement acid mine drainage management to minimize the adverse impact of acid mine drainage in pit lakes.

An immediate understanding of the geochemical characteristics of leachates from pit wall rocks, which control the overall mine water quality, may provide ample time for stakeholders to make immediate corrective planning and management to meet water quality criteria for pit lakes successfully.

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4. Conclusion

From the above results, we can draw the following conclusion. Four samples (IPD-01, IPD-02, PW-01, and PW-02) are characterized as PAF materials due to high TS value, absence of acid neutralizing capacity, presence of pyrite as acid-forming mineral, and low overall leachates' pH value obtained from the kinetic test (pH <3,00) while 2 other materials characterized as PAF-low capacity (FB-02) and non-acid forming materials (FB-01). Therefore, geochemical characterization, including static test, kinetic test, and mineralogical and elemental composition analysis, provides ample information for geochemical modeling of water quality of pit lake development.

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