Evaluation of Acid Mine Drainage Characterization for Predicting Post Drainage Water Quality in Coal Mines

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Abstract

In the surface coal mine, coal is extracted by removing topsoil and overburden above the coal seam layer. The thickness of the coal seam is various, depending on the geological formation of coal sedimentation. In most cases, more than several meters of the seams could exist on the sedimentation of coal. Therefore, during the extraction of coal, the reduction of surface level is unavoidable. As the consequences, a vast hole in the surface, usually called as a void, is formed and develops into a water body to the surrounding environment. Acid mine drainage (AMD) is extremely dangerous because of its low pH (usually below 5) and high concentration of heavy metals, sulfate and salinity. When the disturbed surfaces, such as pit walls and front mining, are exposed to the air and leached by water, AMD will occur due to the abundant availability of sulfide minerals. Accumulation of acidic water in the void could happen. Thus, the study about the assessment of water quality post-mining drainage along with the impact of surface change to the ecosystem, is prominent to be conducted. This paper evaluates AMD characterization of rock samples by using static test, consists of paste pH, Acid Base Accounting (ABA) method of balancing the value of acid capacity from Total Sulfur test and neutralization capacity from Acid Neutralizing Capacity (ANC) test and Net Acid Generating (NAG) test for predicting the water quality of post drainage in the void. XRD analysis was also conducted to discuss mineralogy of the samples. Kinetic test was carried out to assess the final acidity production of rock samples. Validation of the predicted result was performed by simulating the leachate water mixing from the result of kinetic test in the PHREEQC Interactive software.

Keywords: Acid Mine Drainage (AMD), open-pit coal mine, geochemical characterization

Introduction

Open-pit mining operation is a common mining method in the world, as well as in Indonesia. This kind of mining operation method has high potential to generate AMD, since sulfide minerals are exposed to the air and water when coal or ore is excavated. AMD causes environmental pollution and threats the ecosystem in water or soil environment by increasing the concentration of heavy metals and other ions. The prevention of AMD formation is generally considered to be a preferable option in economics consideration. Prevention of AMD is always better than treatment since various choices to avoid AMD are available when it has not been generated yet. Therefore, engineers could consider the most suitable way for the treatment of AMD to be applied in the mine site, either economically or based on the availability of technology.

Formation of pit lake happens when open-pit mining activity is ceased, discontinued or abandoned. As a result, a vast hole is formed and usually called as void. This happens because during the mining operation, dewatering activity is always conducted to remove the water that fills inside the pit of mining. Dewatering is performed to maintain the mining activity in the pit due to the several reasons. Mining equipment, dump truck for example, needs dry area in order to continue to operate safely. Furthermore, if the front face of mining is completely waterlogged, the operation will be impossible to conduct. However, when the mining activity is not carried out anymore, water rebound happens. Water rebound originates from disturbed groundwater, which flows to a lower level because of the massive removal of the surface layer and dewatering activity. When dewatering is stopped, it leads the groundwater to fill-in the void for maintaining the groundwater level balance. Besides the groundwater, rainwater also fills the void as the runoff in adjacent basin and flows on the pit wall or directly fills the void. During the movement of water, minerals are dissolved and at the same time affected the quality of water. Thus, a void's water quality depends on the quality of groundwater, the mineral composition of wall rocks, the chemistry of the surrounding vadose zone, and the quality and quantity of runoff from the surrounding land (Castro and Moore, 2000). Therefore, this paper discusses the prediction of water quality of post-mining drainage in the void by using the geochemical characterization. The prediction utilizes static test that consists of paste pH, total sulfur and acid neutralizing ca-

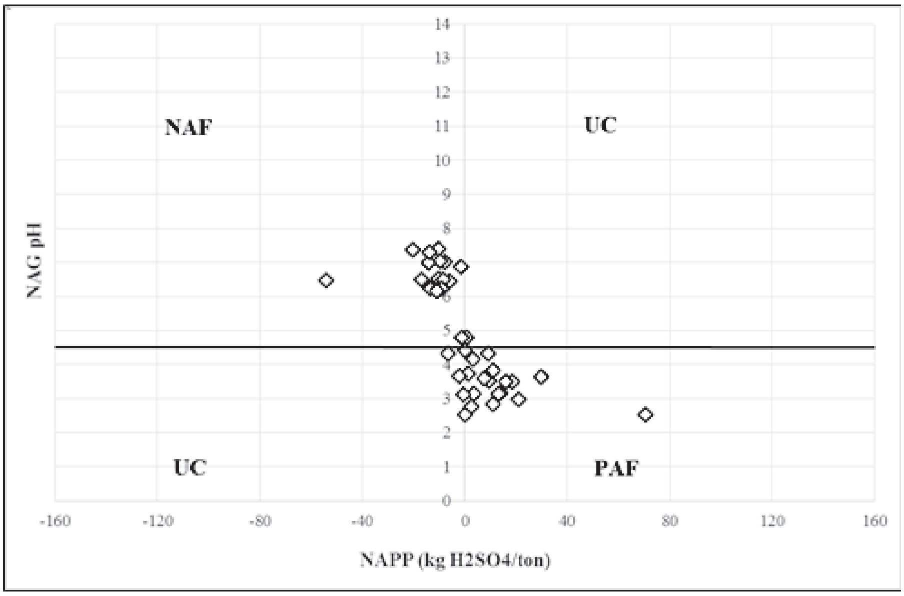

Fig. 1. Geochemical characterization of 37 rock samples based on NAPP (in kg H_2SO_4/ton) and NAG pH value
Rys. 1. Charakterystyka geochemiczna 37 próbek skał bazująca na NAPP (w kg H_2SO_4/tonę) i wartości pH NAG

pacity (ANC) test and net acid generation (NAG) test.

The AMD generally happens due to chemical and electrochemical reaction that produces acidity, ochre and soluble metal ions when sulfide minerals are oxidized in the presences of oxygen. It allows electron transfer in the reduction-oxidation reactions. Then the reaction products are leached by the water, and finally AMD occurs. Pyrite mineral is representing the sulfide mineral in the general equation of the AMD process because of its abundance and high reactivity (higher metal molar ratio) comparing to other sulfide minerals. The following reaction is a pyrite weathering reaction that produces sulfate and also releases soluble ferrous iron (Fe^{2+}) and acidity (H^+) (Younger et al, 2002)

$$2FeS_2(s)+7O_2(aq)+2H_2O \rightarrow 2Fe^{2+}+4SO_4^{2-}+4H^+ \quad (1)$$

When sufficient dissolved oxygen presents, the dissolved ferrous iron is oxidized to ferric iron and consumed the acidity, as in the reaction (2). Microbial activity also plays an important role to accelerate the reaction (2), therefore the rapid formation of ferric iron could be achieved even without the presence of oxygen.

$$2Fe^{2+} + 1/2\ O_2 + 2H^+ \rightarrow 2Fe^{3+} + H_2O \quad (2)$$

Ferric iron can react further and precipitate as iron oxyhydroxide that is usually seen as ochre in water environment, and then it produces greater net production of acidity as can be shown in the reaction (3). Ferric iron can also react with remaining pyrite to produce acidity and also ferrous iron, in the rapid oxidation reaction compare to oxidation reaction with oxygen (reaction (4)).

$$2Fe^{3+} + 6H_2O \rightarrow 2Fe(OH)_3(s) + 6H^+ \quad (3)$$

$$14Fe^{3+} + FeS_2(s) + 8H_2O \rightarrow 2SO_4^{2-} + 15Fe^{2+}\ 16H^+ \quad (4)$$

Follows AMD mechanism above, drainage water of the void is generated. Pyrite contributes significantly for high acidity accumulation in the void water. Other minerals also have roles as the main sources of mine water contamination as well as acid consumption.

Materials and methods

Sampling for this study was conducted on the coal mining site that belongs to PT Arutmin Indonesia (PTAI) in Batulicin region, Kalimantan Island. Rock was sampled in Pit Mangkalapi, which are divided into three parts: Pit Mangkalapi 1, 2 and 3. This research was focused in Pit Mangkalapi 2 because this pit has been already in the final stage and the mining activity will be stopped in two months after pit observation. In order to investigate the capacity of AMD generation of rock materials in this pit, rock materials in the pit wall area of block 33 were sampled vertically. 37 samples were collected from high wall pit, representing the variation of lithology of this area. Rainwater sample was also collected to conduct the water quality analysis, as major water filler in the void. Groundwater occur-

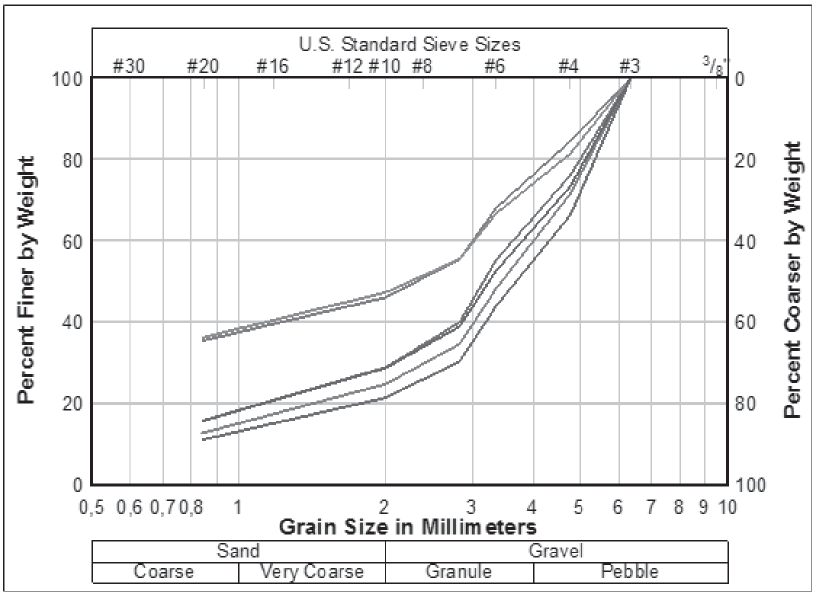

Fig. 2. Particle size distribution of kinetic test samples

Rys. 2. Krzywa składu ziarnowego próbek do badań kinetycznych

rence was neglected in this study on the assumption that water quality in the void is not affected by it.

Static test was carried out to analyze geochemical characterization of rock samples. This test was utilized as an initial test to characterize geochemical properties of rock samples. Geochemical characterization is based on the balance of acid generating components, from sulfide mineral, and acid consumption components, for example carbonate mineral, within the rock sample. This series of tests consists of total sulfur (TS), acid neutralizing capacity (ANC), paste pH and net acid generating (NAG) test that follow the standard in AMIRA International ARD Test Handbook P381A. The result of total sulfur becomes maximum potential of acidity (MPA) value of the rock sample while the balance result of MPA and ANC test becomes net acid producing potential (NAPP). This acid-producing balance calculation is also known as Acid Base Accounting (ABA) method. The mineral compositions of samples were analyzed using X-ray Diffraction (XRD) test as the secondary data to support the result of static test. Furthermore, kinetic test (Free Draining Column Leach test) was also conducted with selected samples. Sample selection was based on their potential of acid production. Kinetic test was carried out to validate results of static test and to determine the oxidation rate of AMD through the analysis of leachate water quality. Analysis of leachate water quality was provided by following Standard Methods for The Examination of Water and Wastewater (SMEWW) and SNI (National Standards of Indonesia). Simulation of leachate water quality was performed with several ratios of acid producing and non-acid producing classification by using PHREEQC Interactive software.

Results and discussion

The paste pH results showed that 15 samples had pH < 5 and 22 samples had pH > 5, with the average pH value was 6.01. The measurement of paste pH shows the natural oxidation that already happened to the rock material when the test was conducted. It means that nearly half of the total samples had been oxidized naturally, thus they were possibly classified as potentially acid forming (PAF) material. While for the rest of samples, there were three possible conditions: sample had not been oxidized yet because of the slow reaction rate, sample had been oxidized and neutralizing material consumed the producing acid, or sample had a little or no sulfide mineral, thus acid was not produced. The rock material was classified as non-acid forming (NAF) material if neutralizing capacity is higher than acid producing capacity and/or a little or no sulfide minerals within the rock.

Based on the result of NAPP and NAG pH value, geochemical characterization can be analyzed. If the sample has a positive value of NAPP (NAPP > 0) and NAG pH value is below 4.5 (NAG pH < 4.5), rock sample is categorized as PAF. In contrary, if the NAPP shows negative value (NAPP < 0) and NAG pH value is above 4.5 (NAG pH > 4.5), then the rock sample is categorized as NAF. Uncertain condition can also happen when the result of static tests shows inconsistency, thus the sample is cat-

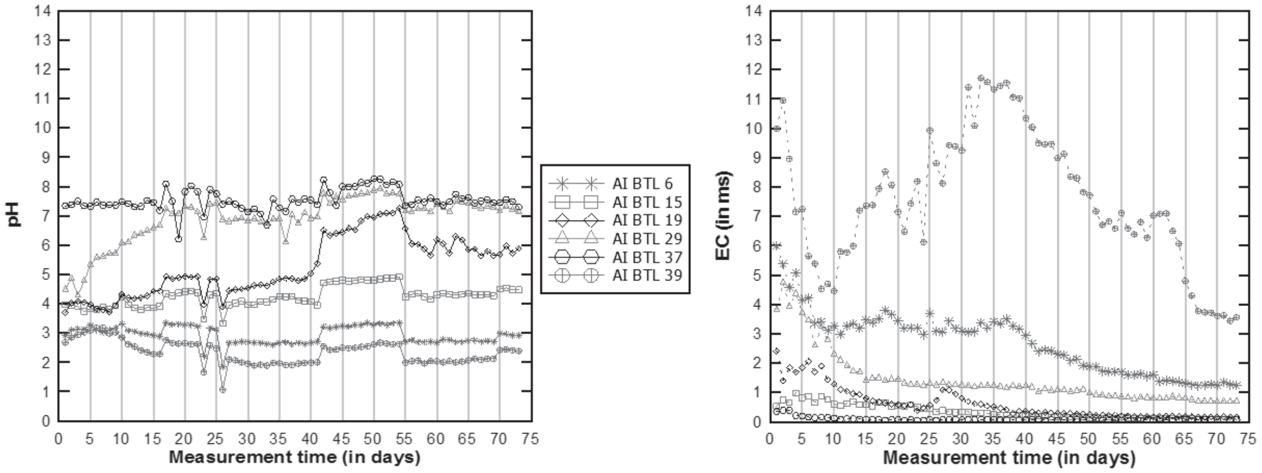

Fig. 3. Free Draining Column Leach test measurement

Rys. 3. Kolumna do badania drenażu

egorized as UC (uncertain). For assessing the acid-generating potential, the result of paste pH value and the mineralogical analysis can be used to determine the rock capacity. Geochemical characterization based on the above explanation is provided in the Figure 1.

As shown in the Figure 1, PAF rock samples were dominant compared to NAF rock samples. 17 samples were categorized as PAF, 16 samples were NAF and 4 samples were UC. PAF samples had quite high acid-producing capacity, as the samples slightly spread in the PAF area with various values of NAPP and low NAG pH. The highest value of NAPP was 70.68 kg H_2SO_4/ton with the lowest NAG pH value was 2.53. The average value of the NAG pH of PAF samples was 3.35 and the NAPP was 14.24 kg H_2SO_4/ton. While in the NAF quadrant, the majority of the samples was concentrated in one area, which means the acid producing capacity was quite similar to each other. The highest NAG pH of samples in NAF quadrant only reached 7.38 with -20.20 kg H_2SO_4 ton NAPP and the lowest NAPP value was -54.13 kg H_2SO_4/ton with NAG pH value was 6.47. The average value of the NAG pH of NAF samples was 6.62 while the NAPP was -12.93 kg H_2SO_4/ton. This implied that NAF rock samples tend to be near neutral capacity.

Based on the static test, it was observed that higher acidity is produced than acid consumption in the future, because in total the existence of PAF samples were larger than NAF samples. Moreover, the NAPP value in average showed that NAF capacity in acid consumption/neutralizes the acidity was not sufficient enough to neutralize the acid-producing capacity of PAF. Therefore, buffering capacity of the void water is not able to maintain near-neutral pH. Based on the static test result, it can be concluded that void Mangkalapi Pit 2 has a high probability to produce acidic water pit lake during the post-mining stage.

In order to confirm the results of static test, kinetic test was carried out for 6 rock samples which consist of: AI BTL 6, AI BTL 15, AI BTL 19, AI BTL 29, AI BTL 37 and AI BTL 39. Before conducting kinetic test, these samples were analyzed for its particle size distribution and mineralogical analysis by XRD test. The result of particle size distribution is presented in the Figure 2. It was observed that all of rock samples were dominated by gravel and sand particles with 4 samples clay content were less than 20%, while two samples were less than 40% of clay content. Median diameters (d50) of samples were about 2.4 to 3.8 mm. Based on the XRD analysis, it was observed that major minerals in the rock samples were quartz, muscovite, albite, kaolinite, montmorilonite and pyrite.

FDCL test was conducted on a daily basis for 73 days by daily spraying of distilled water and measurement of leachate water. The measurement consisted of pH, ORP (oxidation-reduction potential), TDS (total dissolved solid) and EC (electrical conductivity) values. Results of pH and EC are provided in the Figure 4. Based on static tests, all of the samples were categorized as PAF rock material. Most of the leachate water from 6 samples had shown concordant result with static test. However, in the simulation of leaching test, one sample showed the behavior of being NAF material.

As indicated in the static test, the value of AI BTL 37 NAG pH was 2.54 while paste pH was 7.00, suggests that this sample had a lower NAG pH but the neutral value of paste pH. Moreover, the NAPP value was only 0.04 kg 0/ton, which means that this sample was considerable as NAF material.

Tab. 1. The result of mixing simulation by PHREEQC

Tab. 1. Wyniki symulacji za pomocą PHREEQC

Parameter	PAF : NAF Ratio								
	1:9	2:8	3:7	4:6	5:5	6:4	7:3	8:2	9:1
pH	3.800	3.710	3.640	3.580	3.530	3.480	3.450	3.410	3.370
Ca *	0.162	0.317	0.473	0.629	0.784	0.939	1.095	1.250	1.406
Fe *	1.309	2.617	3.925	5.233	6.539	7.847	9.154	10.462	11.770
K *	0.004	0.006	0.007	0.008	0.009	0.010	0.012	0.013	0.014
Mg *	0.117	0.187	0.257	0.328	0.398	0.468	0.538	0.608	0.678
Mn *	0.020	0.039	0.058	0.077	0.096	0.115	0.1335	0.152	0.171
Na *	0.018	0.022	0.026	0.029	0.033	0.036	0.040	0.043	0.047
Al *	0.000	0.001	0.001	0.001	0.002	0.002	0.002	0.003	0.003

Supported by data from measurement of paste pH, it was understandable that AI BTL 37 result of kinetic test was classified as NAF material. AI BTL 29 had a similar trend with AI BTL 37 even though in the initial measurement the pH value had quite a low result. The measurement of pH from AI BTL 29 was increasing rapidly day by day until it reached stability near neutral pH, around 7.00. It was also supported by the measurement of EC value, which reflects to the total amount of dissolved ions in the leachate. EC value has an opposite order with the pH value, where the lower pH has resulted in the higher EC value. It means that when pH of leachate water decreases, the total amount of dissolved ions increases that gives more electric conductivity in the water. Initially, the EC value of AI BTL 29 was higher compared to other samples, but it rapidly decreased then finally reached stability after 20 days. In this case, AI BTL 29 could be considered as PAF with low capacity. The rest of samples showed the behavior of PAF material, with low $pH < 5$ and quite high EC value. From the kinetic test results, it was concluded that the PAF samples in this test can be divided into three major groups as follows: small pH (pH 2–3) and large EC, i.e. AI BTL 06 and 39; medium EC and pH value (pH 3–5), i.e. AI BTL 15 and 19; and high pH value ($pH > 6$) and small EC, i.e. AI BTL 37 and 29.

Based on the data above, mixing simulation was conducted by using PHREEQC Interactive software. Mixing simulation is a mix of leachate water from the kinetic test by using chemical analysis simulation. This simulation is intended to be able to see an estimation of the predicted result of post-mining drainage water within the void by using the leachate water quality parameters, such as PH, ORP, EC, and heavy metal concentrations. Chemical reactions that happened in the reality should be in accordance with the result of simulation in the laboratory. From the classification of leachate water before, group that had high pH value and low EC together with distillate water (input water during the kinetic test as rainwater) were categorized as NAF. The other two groups were categorized as PAF. Then mixing simulation was carried out with various ratios of PAF and NAF as shown in the Table 1.

Based on the Table 1, the result of water in the void had a pH value ranging from 3.30 to 3.80, which was acidic to the environment. It had been resulted low pH value even though the PAF ratio was 10% of the total amount of water mixing. As the PAF portion increased, the pH decreased with increased iron concentration and other metal contents in the quality of leachate water. This could be explained by referring to the result of static test. It shows that the neutralizing capacity of rock was low on the Batulicin mine site. Therefore, it was in concordance with the mixing result, which resulted acidic water. Therefore, further investigation, evaluation and plan of treatment strategy are needed for pit lake in Batulicin in order to assess the prediction better and prevent the AMD generates.

Conclusions

Overall, based on the result of static test and validation of characterization from kinetic test, it can be assumed that static test could be used for preliminary prediction of post-drainage water in the void. However, challenges will be encountered when the samples are classified into “uncertain”. In this case, it is important to conduct kinetic test to know the details of acid generation of samples. Assessment from static test can be supported and also validated by kinetic test.

Study to increase the reliability of static test for prediction of post-mining drainage water is needed in the future. Mineralogical analysis and geological conformity also can be used to increase the confidence rate of the result of geochemical characterization. Moreover, prediction of post-mining drainage water quality can be conducted by using the PHREEQC to simulate chemical reaction within the mineral in rock samples with rainwater.

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Ocena właściwości kwaśnego odcieku kopalnianego na potrzeby prognozy jakości wody po drenażu w kopalniach węglowych

W kopalni odkrywkowej węgla węgiel wydobywany jest przez usunięcie nadkładu oraz wierzchniej warstwy ziemi znad warstwy pokładu węgla. Grubość pokładu węgla jest zróżnicowana zależnie od geologicznej formacji, w której zaszła sedymentacja węgla. W większości przypadków, ponad kilka metrów nadkładu może znajdować się nad warstwami węgla. Zatem, podczas procesu wydobycia węgla, strata na poziomie powierzchni jest nieunikniona. W rezultacie powstaje szerokie wyrobisko w powierzchni, zwykle zwane odkrywką kopalni, która następnie zasila otaczające ją środowisko w wodę. Kwaśny Drenaż Kopalniany (ang. skrót AMD) jest ekstremalnie niebezpieczny ze względu na niski poziom pH (zazwyczaj poniżej 5), wysokie zasolenie i wysokie stężenie metali ciężkich oraz siarczków. Gdy powierzchnie, takie jak po urabianiu ścianowym oraz czołowym, są narażone na działanie powietrza oraz ługowanie wodą, powstaje kwaśny drenaż kopalniany o pH wynikającym z występowania dużej ilości minerałów siarczkowych. Następuje nagromadzenie kwaśnej wody w wyrobisku. Dlatego bardzo ważne jest przeprowadzenie badań nad oceną jakości wody po drenażu kopalnianym wraz z wpływem zmian powierzchniowych na ekosystem. Niniejsza praca określa charakterystykę kwaśnego drenażu kopalnianego z próbek skały przy użyciu testu statycznego, składającego się z testu odczynu pH, metod obliczania bilansu kwasowego (ang. skrót ABA) w celu kontroli kwasowości przy określaniu poziomu siarki całkowitej oraz zdolności zobojętniania podczas testu sprawdzającego Zdolność do Zobojętniania Kwasu (ang. skrót ANC), a także przeprowadzono test sprawdzający Ilość Netto Kwasu Wytwarzanego(ang. skrót NAG), aby móc określać jakość wody po drenażu w odkrywce. Przeprowadzono również analizę dyfrakcji rentgenowskiej na potrzeby omówienia składu mineralogicznego próbek. Wykonano też test kinetyczny, aby określić końcową ilość kwasu w próbkach skały. Następnie zestawiono przewidywane wyniki, potwierdzone przez symulację mieszania się odcieków wodnych, wraz z wynikami testu kinetycznego przeprowadzonego za pomocą oprogramowania PHREEQC Interactive.

Słowa kluczowe: Kwaśny Drenaż Kopalniany (AMD), kopalnia odkrywkowa węgla, określenie właściwości geochemicznych