Placement of Waste Rocks in Waste Dump for Prevention of Acid Mine Drainage (AMD) by Cover System in Open Cast Coal Mine: Effects of Water Quality on AMD

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Abstract

Acid Mine Drainage (AMD) attributed to mine operation is considered one of serious environmental problems in the world. Cover system is utilized as an environmentally-friendly and an effective way for prevention of AMD in many cases in open cast coal mines in Indonesia. Waste rocks are classified into Potentially Acid Forming (PAF) or Non Acid Forming (NAF) on the basis of geochemical properties of rocks. PAF which is a cause of AMD is covered with NAF which is considered rocks unrelated to AMD at waste dump in order to prevent the contact of PAF with water and oxygen. The placement of backfill of waste rocks in waste dump is determined only by the classification at the aim of the prevention of AMD. According to past studies, pH affects the progress of AMD through the change of dissolution behavior of metals. In regard to the occurrence of AMD on the inside of waste dump, waste rocks in the lower part of waste dump are possibly affected by leachate from the upper part. Thus, the placement of waste rocks in waste dump need to be discussed in terms of not only the types of PAF or NAF but also the effects of water quality on the occurrence of AMD. This study presents the effects of pH on the progress of AMD with the results of leaching test under various pH conditions using rock samples taken in coal mine: pH was set at 3.0, 6.0, and 8.0. The results indicate that pH is not important factor as compared to the supply of oxygen to discuss the progress of AMD for a long term. In other words, the placement of waste rocks in cover system has to be determined by considering not so much the effect of water quality as the supply of oxygen.

Keywords: Acid Mine Drainage (AMD), cover system, waste dump, waste rock placement, effects of pH

Introduction

The exposure of sulfide minerals to oxygen and water by resources development results in Acid Mine Drainage (AMD). The acidic water causes negative impacts on the nature due to low pH and/or a high concentration of heavy metals. Indonesia, which is one of the largest coal producing states in the world, is facing an increase in the number of AMD in recent years. Heavy rain and high temperature in the tropical climate make progress on the AMD issue in Indonesia. Thus, AMD has to be solved as soon as possible in terms of environmental conservation in the country.

The countermeasures against AMD are categorized into two types: measures for prevention of AMD and treatment of acidic water (Johnson and Hallberg, 2005). Cover system which is categorized into the former is widely implemented in open cast coal mines in Indonesia owing to low cost and the simplicity of maintenance as shown in Figure 1. Waste rocks produced during mining operation are categorized into Potentially Acid Forming (PAF) or Non Acid Forming (NAF) on the basis of geochemical properties of rocks in the system: PAF is the rock which results in AMD

and NAF is the rock unrelated to AMD. PAF is covered with NAF and topsoil in order to prevent the contact of PAF to water and oxygen, aiming at prevention of AMD. This classification of waste rocks is conducted by considering Net Acid Producing Potential (NAPP) and Net Acid Generating (NAG) pH in rocks through a series of geochemical tests (Sobek et al., 1978; Miller et al., 1997). The backfill of waste rocks in waste dump is currently conducted based on only the classification of PAF or NAF. However, the placement of waste rocks in waste dump has to be discussed in more detail. Matsumoto et al. (2015) have showed that the supply of oxygen affected the progress of AMD more than the water flow (Matsumoto et al., 2015). Meanwhile, water quality is another important factor in order to discuss the progress of AMD since pH affects the progress through the change of dissolution behavior of metals according to Abreu et al. (2014) (Abreu et al., 2014). There are, moreover, many types of PAF even if they are classified into PAF in the same way: they have a different level of acid producing potential (Pope and Weber, 2013). In regard to the occurrence of AMD on the inside of waste dump, rocks in the lower part of waste dump are pos-
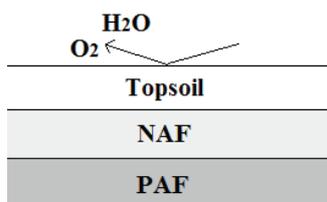
Fig. 1 Schematic view of cover system

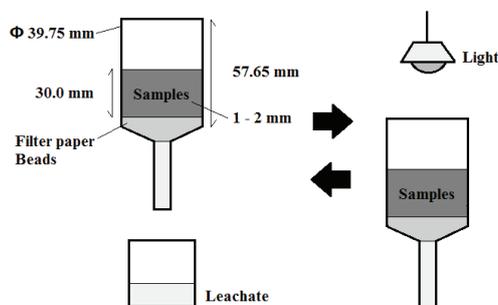Rys. 1 Schemat systemu lokowaniaodpadów

Fig. 2 Schematic view of leaching test

Rys. 2 Schemat testu ługowania

sibly affected by leachate from the upper part. In short, the placement of waste rocks in waste dump need to be discussed by considering the progress of AMD by water quality. Thus, this study presents the effects of pH on the progress of AMD with the results of leaching test under various pH conditions using rock samples taken in coal mine: pH was set at 3.0, 6.0, and 8.0.

Materials and method
Sample analysis

Four types of PAF were taken in pit in open cast coal mine in Indonesia. They had been preliminarily classified into PAF by geological investigation in this mine. They were sealed in a plastic bag to prevent the weathering of rocks and sent to a laboratory after the sampling. They were dried in nitrogen atmosphere at 80°C for 24 hours, followed by XRF analysis to understand chemical composition of the samples. Additionally, NAG test, Acid Base Accounting (ABA) test, and paste pH and EC test were conducted with the samples in accordance with the AMIRA standard proposed in 2002 (Sobek et al., 1978; AMIRA P387A, 2002). NAPP and NAG pH which indicate acid producing potential of the samples were calculated based on the results in order to discuss the potential to cause AMD.

To discuss the neutralization by carbonate in the samples, carbonate was quantified by Bernard Calcimeter test (Muller and Gatsner, 1971). The amount of carbonate is quantified by measuring the change of water level caused by produced carbon dioxide gas when the carbonate reacts with hydrochloric acid in the test. Additionally, sequential extraction with acids was performed with the samples to understand the form of sulfur and iron in the samples. Hydrochloric acid, hydrogen fluoride, and nitric acid were utilized for dissolution of the samples by reference to past studies (Huerta-Diaz and Morse, 1990; Matsumoto et al., 2015). In this analysis, readily-soluble minerals are obtained at the step with hydrochloric acid, and silicate minerals are obtained at the step with hydrogen fluoride, and sulfide minerals are dissolved at the step with nitric acid according to past research (Sasaki et al., 2002).

Leaching test

Column leaching test was performed by using deionized water adjusted to pH 3.0, 6.0, and 8.0 with nitric acid and sodium hydroxide. Figure 2 shows the schematic view of the leaching test. 1–2 mm of rock samples were packed until 30.0 mm height of the column at 60–63% of porosity. The height of the column is 57.65 mm and the diameter is 39.75 mm, and 1 mm of beads and filter paper were set at the bottom of the columns to prevent the leakage of samples. 250 mL of the deionized water was supplied into the columns and the leachate from the bottom of the columns was sampled. The pH and EC were measured by pH meter (TOADKK) HM-21P and CM-21P in addition to the permeability based on the time of leaching in the columns. After the leaching, the samples were dried by artificial lighting for 24 hours as shown in Figure 2. This cycle of wetting and drying was repeated until 30 times in this leaching test. The total amount of the supplied water corresponds approximately to the amount of rainfall during approximately 1 year in consideration of annual rainfall in Indonesia.
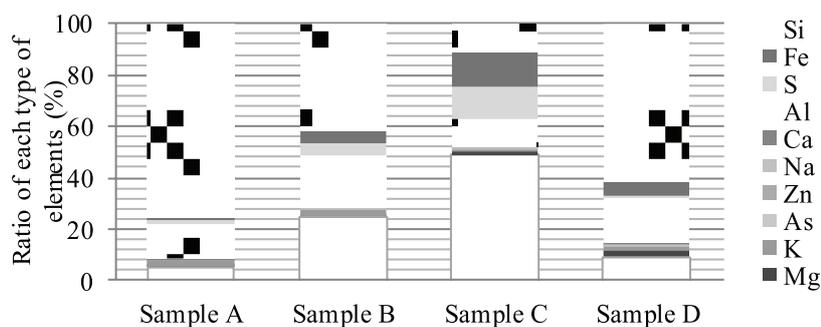
Fig. 3 Chemical composition of the samples

Rys. 3 Skład chemiczny próbek

Tab. 1 Geochemical properties of the samples

Tab. 1 Właściwości geochemiczne próbek

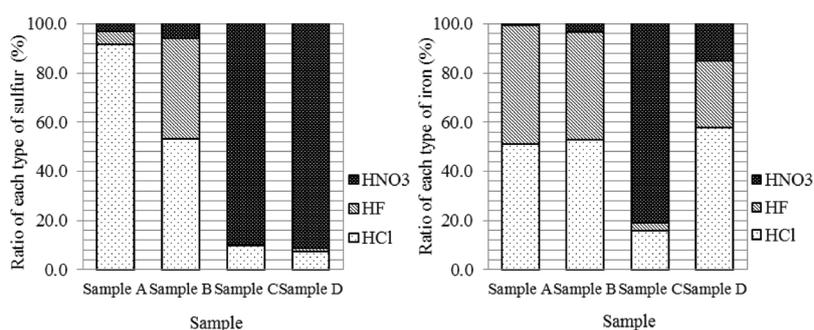| Sample	Paste pH	Paste EC (mS/cm)	Sulfur content (%)	NAPP (kg H_2SO_4/ton)	NAG pH	$CaCO_3$ (%)
A	3.10	2.10	0.90	27.4	2.80	0.496
B	1.74	10.30	4.99	152.8	1.47	0.298
C	1.21	136.00	12.55	383.9	1.04	0.233
D	7.84	1.36	0.77	3.2	3.56	1.583

Fig. 4 Each form of sulfur and iron in the samples

Rys. 4 Postać siarki i żelaza w próbkach

Results and discussion

The chemical composition of the samples is shown in Figure 3 and the results of paste pH and EC test, ABA test, and Bernard Calcimeter test are summarized in Table 1. The results of sample A, B, and C in Table 1 were shown by reference to previous study since they were used in another experiment (Matsumoto et al., 2015). They consisted of iron and sulfur which compose pyrite (FeS2) and they showed a positive NAPP in the results: positive NAPP indicates that the rock causes AMD. According to the classification with NAPP and NAG pH in the mine, all samples were, furthermore, categorized into PAF. In Figure 3, more than 50% of sample A and D consisted of Si, and sample B and C were composed of more iron and sulfur than the others. A high content of iron and sulfur in sample B and C was consistent with high NAPP and low NAG pH in the samples. Most

of elements were categorized into others in sample C since it contained much water more than the others. A high content of carbonate in sample D in Table 1 suggests that the rock may have acid neutralizing capacity. Hence, there is difference in chemical composition and acid producing potential in rocks even if they are classified into PAF in the same way.

Figure 4 shows the result of sequential extraction with acids. The samples can be categorized into 2 types in the result: sample A and B in which more than 50% of sulfur consist of readily-soluble sulfur and sample C and D in which more than 90% of sulfur consist of sulfide minerals. More than 80% of sulfur and iron consist of sulfide minerals in sample C, suggesting that sample C consists of a large amount of pyrite (FeS2) in comparison with the others. On the other hand, most of iron was extracted at the step with hydrogen fluoride
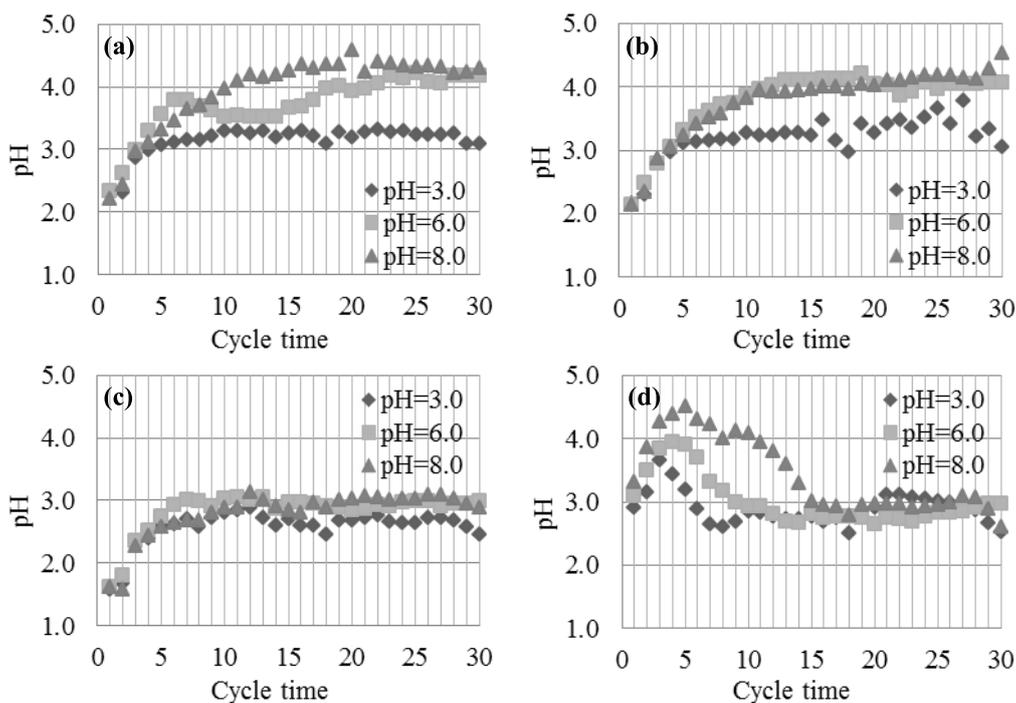
Fig. 5 Change of pH under various pH conditions in leaching test: (a) sample A; (b) sample B; (c) sample C; (d) sample D

Rys. 5 Zmiana odczynu pH podczas testu ługowania: (a) próbka A, (b) próbka B, (c) próbka C, (d) próbka D

and hydrochloric acid contrary to high content of sulfur at the step with nitric acid in sample D, indicating that most of sulfur consist of sulfide minerals except for pyrite.

The change of pH under various pH conditions in the leaching test is shown in Figure 5. Sample A and B showed a similar trend in the change of pH until 5 times of leaching, followed by a steady change at pH > 3 with a slight difference in pH in each pH condition. The water quality in leachate was, apparently, improved every cycle of leaching after dissolution of readily-soluble sulfur at the early stage of leaching until 5 times, leading to a steady change at pH > 3. The discussion of the difference in water quality derived from the form of sulfur in rocks in the previous study is consistent with the result (Matsumoto et al., 2015).

There was not significant difference in the change of pH in sample C; meanwhile, the change of pH varied until 15 times of leaching depending on the difference of pH in the supplied water in sample D. Additionally, the pH in sample C and D have been changed at pH < 3 at a later stage of leaching. By considering a high content of carbonate in sample D, the peak of pH which varied depending on pH in the supplied water was due to the neutralization by carbonate. The difference of the cycle time in the peak was, besides, caused by combined effect of neutralization by carbonate and alkali condition in the supplied water: the pH decreased less than 3 after 5 time of leaching under the condition of pH = 3 in the supplied water, and it decreased less than

3 after 15 time under pH = 8 in the supplied water. Although the rocks in which most of sulfur consist of sulfide such as sample D showed a lag time in the change of pH depending on the content of carbonate, the pH converged at pH = 3 over time. The lag time in sample D corresponds to 5 times of the leaching, and it corresponds to the amount of rainfall during 2 months in Indonesia. This indicates that the water quality derived from waste rocks can significantly change depending on the pH in the supplied water during 2 months, suggesting that the water quality in the supplied water should be monitored in addition to that in waste water to discuss the change of water quality in AMD from waste dump. However, the water quality in the supplied water is not a significant factor affecting AMD in terms of long-term prevention of AMD since the pH finally converged at a similar value.

Figure 6 shows the change of permeability under various pH conditions. There was no difference in the permeability by more than 10-1 cm/s under the conditions. This indicates that the permeability was not affected by the difference of pH in the supplied water. The permeability was, besides, drastically decreased at the early stage of leaching in sample A, B, and D, suggesting that it was caused by weathering of rocks through wetting and drying cycles. The weathering of rocks through wetting and drying cycles causes the decrease of particle size and of permeability according to past research (Sadisun et al., 2003). Thus, the physical performance in cover layer in terms of permeability
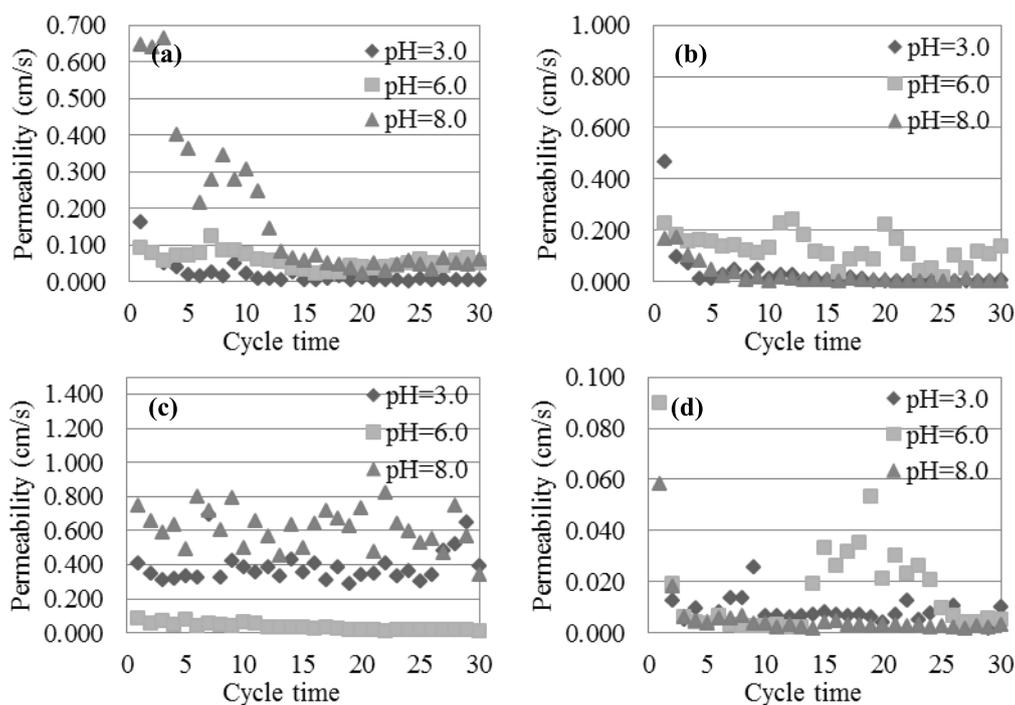
Fig. 6 Change of permeability under various pH conditions in leaching test: (a) sample A; (b) sample B; (c) sample C; (d) sample D

Rys. 6 Zmiana przepuszczalności podczas testu ługowania: (a) próbka A, (b) próbka B, (c) próbka C, (d) próbka D

was not affected by the water quality in supplied water based on the result.

In regard to prevention of AMD derived from waste dump for a long term, the water quality in supplied water to PAF is not important factor. By considering the results in previous study (Matsumoto et al., 2015), the supply of oxygen to the inside of waste dump should be taken into account more than the difference in water quality of supplied water in order to discuss the occurrence of AMD on the inside of waste dump.

Conclusions

The main results are summarized as follows:

i)   The water quality in leachate finally converged at a similar value regardless of the difference in the water quality in the supplied water. However, the time lag occurred in the change of water quality at the early stage of leaching due to neutralization by carbonate: it corresponded to the amount of rainfall during 2 months in Indonesia. This indicates that the monitoring of the water quality of the supplied water to waste dump is

necessary in addition to that of waste water from waste dump in order to discuss the progress of AMD on the inside of waste dump within 2 months.

ii)   The physical performance of permeability in cover layer is not significantly affected by the water quality in the supplied water.

iii)   In regard to the backfill of waste rocks in waste dump to prevent AMD, the pH in the supplied water is not important factor as compared to the supply of oxygen to discuss the progress of AMD on the inside of waste dump for a long term. In other words, the placement of waste rocks in cover system has to be decided in consideration of not the effect of water quality in the supplied water but the supply of oxygen.

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Lokowanie odpadów na składowisku odkrywkowej kopalni węgla
w celu zapobiegania kwaśnemu odciekowi z (AMD), wpływ AMD na jakość wody

Kwaśne odcieki z kopalni (AMD) związane z operacjami górniczymi są postrzegane jako jeden z najbardziej poważnych problemów środowiskowych. Przedstawiony system ochrony jest przyjazny dla środowiska i jest efektywnym sposobem na prewencyjne działania wobec AMD w wielu przypadkach dla kopalń odkrywkowych w Indonezji. Odpady górnicze dzieli się na Potencjalnie Tworzące Kwasy (PAF) oraz Nie Tworzące Kwasów (NAF) na podstawie ich właściwości geochemicznych. PAF, będące przyczyną AMD są pokryte NAF, które z kolei są nie związane z AMD i stosowane są w celu uniknięcia kontaktu PAF z wodą i tlenem. Umiejscowienie miejsca podawania odpadów na składowisku jest uwarunkowane jedynie lokalizacją związaną z potencjalnym wpływem AMD. Według przeprowadzonych dotychczas badań, odczyn pH wpływa na AMD poprzez zmianę rozpuszczalności metali. Ze względu na obecność AMD wewnątrz składowiska, odpady znajdujące się w dolnej części składowiska są narażone na działanie odcieków z górnej części. Zatem, lokowanie odpadów na składowisku musi uwzględniać na nie tylko typy PAF lub NAF, ale także na wpływ jakości wody na występowanie AMD. W artykule przedstwiono analize wpływu pH na postęp AMD wraz z wynikami testów ługowania w warunkach różnej wartości pH – 3,0, 6,0 oraz 8,0. Wyniki wskazują, że pH ma mniej istotny wpły od warunkow utleniania w długim okresie czasu. Sposób lokowania odpadow musi być uzależniony bardziej od dostępności tlenu, mniej od jakości wody.

Słowa klucze: kwaśne odcieki kopalniane (AMD), system ochrony, składowisko odpadów, lokowanie odpadów, wpływ pH