Characterization of Sludge Generated from Acid Mine Drainage Treatment Plants

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Abstract. One of the wastes generated from coal mining area is the voluminous sludge, laden of metals. This sludge comes as precipitate which is produced from acid mine drainage active treatment ponds and always been disposed to the landfill. Limestone is one of the typical pH neutralization agents which is often used to bind the metal content of acid mine drainage in active treatment and will be settled at the bottom of the settling ponds. The goal of this study is to determine the potential utilization of acid mine drainage sludge in order to reduce the environmental problem caused by sludge accumulation so that this could become a valuable material. In this study, physical and chemical characterization from the sludge in solid form was carried out by laboratory analysis using SEM-EDS to see surface morphology, X-Ray Diffraction for mineralogy analysis, the chemical composition was done by using X-Ray Fluorescence and also BET method to see the surface area of the sample. The results of the characterization have shown that acid mine drainage sludge was very promising to be utilized as adsorbent material for removing pollutant in wastewater and further research is needed for the application to the wastewater technology.

1. Introduction

Acid mine drainage has always been one of the mining problems that difficult to avoid. Acid mine drainage is produced due to the contact of mineral sulfides, which are exposed because of mining and piling activities, with the oxygen. The oxidation of mineral sulfides and the presence of water will form oxidation products such as iron ferro, sulphate and acid. This will increase the acidity in water bodies, remarks by decreasing of the pH value. Besides the increasing acidity, this also will lead to the increasement of dissolved metals concentration in the water bodies. Among several sulfide metals, pyrite is the main mineral that causing the acid mine drainage because it is easily to oxide when exposed to oxygen, water, and microorganism [1–4]

Acid mine drainage that has not been treated before it is discarded to the water bodies can cause negative impacts to the environment. Because of the low value of the pH and also the higher content of metals, acid mine drainage has the potential to be poison for the environment, so that acid mine drainage treatment must be done by mining industry. Treatment of acid mine drainage can be done by active and passive methods. Active method is done by using lime to increase the pH so that neutral condition can be achieved and causing the precipitation of dissolved metals as hydroxide [5–7]. Lime is the common neutralization chemical for active treatment and has been chosen because it is commercially available, easy to use, cheap, effective and also easy to manage in terms of health and safety in large scale [8]. This method requires relatively large construction, human assistance and
other supporting instrument in operation. Passive method tends to rely on the natural physical abilities, geochemistry and biological processes of the system without any human assistance in its operation. Passive method usually requires a relatively large area and tend to support active method and post-mining processing [9].

Those acid mine drainage treatment methods will produce sludge with various compositions depending on the treatments, the use of lime and the quality of the water to be treated. Acid mine drainage sludge can be controlled in several options. In mining operations, sludge is often collected into a specific pond or mixed with tailings in a tailings pond. Other options are using the sludge as tailing cover material, dispose it to mining fields, wells and mine backfill. However, it is said that covering the tailings with sludge does not effectively prevent the formation of acid mine drainage because the sludge can dry out and crack and also its alkalinity may not be sufficient to neutralize acidity and prevent metal mobilization. [10]

The main problem related to the management of acid mine sludge is the stability of sludge (chemical and physical) and reservoirs. Stable sludge will not harm the environment and can be disposed of in a long-term storage facility. This stability depends on the degree of resilience in the environment which makes it possible to significantly change the chemical composition of sludge. Also, the next problem is the storage of sludge, which before it is collected, the sludge must undergo several treatments to make it easier to regulate and control and to chemically stabilize the contaminants in it. This sludge collection process requires a lot of costs [7]. Therefore, utilization of the sludge is needed rather than being disposed on the land.

The objective of the paper is to analyze the characterization of acid mine drainage sludge and determine its potential as valuable material. The results of this characterization can be used as supported information of acid mine drainage sludge to provide further challenges and research needs.

2. Materials and methods

AMD sludge was used as the material to be analyzed in this study. This sludge was collected from acid mine drainage treatment site called PIT-3 Barat, Banko Barat site, PT Bukit Asam Tbk., Tanjung Enim, where it is actively treated with limestone. The collected sludge was dried using oven at 105°C, crushed, and then sieved through a fine screen (100 mesh) to get the uniform size. [11]

The chemical composition of dried acid mine drainage sludge was determined by using XRF tools called Panalytical Epsilon 1. The process was operated at the voltage of 50 kV using Ag as the source. Minerals in dried acid mine drainage sludge were identified using XRD tools from PANalytical X’Pert Pro MPD which is equipped by Fast Detector X’Celerator that can measure the sample faster and more accurate. The X-ray worked by using Cu K(α) 1.54 A filtered radiation in 40 kV and 30 mA for the current. Step scans were run in continuous mode over the range of 10-90°2θ, with 0.02° stepping size. The patterns were interpreted by using application called HighScore Plus by PANalytical B.V 2012. Both XRF and XRD analysis were done at UPP IPD MIPA UI Research Laboratory.

Structural morphology of the sample was identified by Scanning Electron Microscopy equipped with Energy Dispersive X-ray Spectroscopy (EDS). A SEM tool called Inspect F50 by FEI was used. BET (Brunauer-Emmet-Teller) method was used to determine specific surface area of the sample [12].

This method was done by analyzing the dried acid mine drainage sludge sample by N₂ adsorption isotherm at 120°C for degassing temperature. This laboratory analysis was done by using instrument at LIPI Kimia Laboratory Serpong.

3. Results and Discussion

XRF analysis of solid acid mine drainage sludge is done by assuming all the metals existed as elemental form (determination of 26 elements). The composition of the sludge depends on the source of mine drainage where the treatment contaminated water from coal mines has less toxic element rather than those from the polymetallic mines [13-15]. Table 1 showed that the sample contains Si (39.77 %), Fe (33.1 %) and Al (12.73 %) as the major constituents. The content of S, K, Ca and Ti are between 1.5 to 6.0 %. The other elements are all in trace amounts which are respectively below 1% in
the concentration. Iron and aluminium in the sludge are the results of neutralization process of acid mine drainage water where they both are dissolved metals and becomes precipitate along the pH adjustment. Besides Fe and Al, the sample also contains silica. Silica has known as common impurities in the sludge. Silica comes from the soils and sediment and the high content of it in the sludge probably due to inadvertent sediment contamination. [16]

Table 1. Composition of dried Acid Mine Drainage Sludge sample from PIT-3 Barat, Banko Barat site, PT Bukit Asam Tbk., Tanjung Enim

| Element | Concentration (%) | Element | Concentration (%) | Element | Concentration (%) |
|---------|-------------------|---------|-------------------|---------|-------------------|
| Al      | 12.73             | Cu      | 0.03              | V       | 0.07              |
| Si      | 39.77             | Zn      | 0.11              | Cr      | 0.04              |
| P       | 0.66              | Ga      | 0.02              | Mn      | 0.24              |
| S       | 1.66              | As      | 0.01              | Sn      | 0.02              |
| Cl      | 0.74              | Nb      | 0.08              | Eu      | 0.20              |
| K       | 5.59              | Sr      | 0.09              | Yb      | 0.03              |
| Ca      | 1.97              | Y       | 0.03              | Re      | 0.00              |
| Ti      | 2.53              | Zr      | 0.22              | Pb      | 0.03              |
| Fe      | 33.10             | Ni      | 0.04              |         |                   |

Figure 1 showed SEM images of dried acid mine drainage sludge from 2 different resolution at 2,500 x and 10,000 x. They all revealed that the samples are giving mesh like structure, slightly porous with the outer edges had uneven surface with mostly flake-like appearance. The flaky structure around the solid material indicates that it contains numbers of silica oxide and for the spongy porous assumed to be composed of iron oxide particles [17].

Figure 1. SEM images of dried acid mine drainage sludge at (a) 2,500 x resolution and (b) 10,000 x resolution

Figure 2 showed the details of one of the particles from solid acid mine drainage sludge which explained also by the graphic representing the element concentration as a result of image interpretation by EDS. It shows that this particle has higher peaks in concentration of Si (28.34 wt%), O (38.33 wt%), and Al (17.16 wt%), also lower peaks for concentration (<7.5 wt%) of Mg, Fe and K. From
Figure 2, we can conclude that both XRF and SEM-EDS has correlation in showing the composition of the dried acid mine drainage sludge sample.

![Figure 2](image)

**Figure 2.** (a) SEM image of particle and (b) its interpretation by EDS in graphic of dried acid mine drainage sludge composition

XRD analysis was done to determine the phase composition of the dried acid mine drainage sample. The results in Figure 3 showed that the sample contained magnetite, quartz, kaolinite and metahalloysite. Quartz particles dominated the sample which probably a result of contamination during sampling of natural environment [18] and magnetite were found in a small amount as represent of iron content. Kaolinite and metahalloysite also are the parts of the sediments which majorly formed by clays and silts that indicate alumino-silicate minerals. [19]

![XRD graph](image)

**Figure 3.** XRD graphic analysis of dried acid mine drainage sludge

Specific surface area, pore volume and pore size of dried acid mine drainage sludge sample also being identified by BET method and the results are each respectively 22.60±0.199 m$^2$/g, 0.060476 cm$^3$/g and 10.70614 nm. The higher value of those characteristics from BET method analyses are achieved, then the higher is its sorption capacity possibility. Pretreatment such as activation by chemical, thermal or combination of them could be performed in order to improve the adsorption
capacity and efficiency. By doing the pretreatment, the surface charges could be changed and undesired organic compounds or competing ions could be removed from the sorbent. [20,21]

From those characterization processes results for this dried acid mine drainage sample that has been described above, there are some possibilities to utilize the sample as adsorbent. From the composition of the sample, it has high concentration of silica, aluminium and iron. Combination of silica and aluminium can be used to make zeolite as adsorbent through some synthesis processes. The composition is quite similar to fly ash which is also categorized as waste material and has been widely used as zeolite raw material [22]. Previous study also has been done where another type of sludge that contain high concentration of Si and Al which are lake sludge [23] and Lapindo mud from Indonesia [24] were carried out to produce zeolites as adsorbent. The content of metals such as Al and Fe in a material also considered as highly adsorbent which make it suitable to remove contaminants. Sludge that composed of iron oxides and/or iron sulfate (oxy) hydroxides can sequester through adsorption and co-precipitation of oxyanions and cations. [25-27]

4. Conclusion
Treatment of acid mine drainage will always compromise with the formation of the sludge. The composition of acid mine drainage sludge can be affected by source of mine drainage flows. Sludge sample from acid mine drainage treatment pond, PIT-3 Barat, Banko Barat site, PT Bukit Asam Tbk., Tanjung Enim is majorly composed of Si, Fe and Al compound and it is described by the results of XRF, SEM-EDS and XRD analyses. BET method also showed that the surface area of the sample is 22.60±0.199 m²/g with pore volume and size respectively are 0.060476 cm³/g and 10.70614 nm. The sludge sample might be contaminated by sediment that contain clays and silts which carried away by storm water flows to the pond, but still could be beneficial as adsorbent. The higher composition of Si and Al could be used to make zeolite which has widely known as adsorbent and the possibility of more Fe present in the sludge could be used to adsorb contaminants such as oxyanions and cations. Pretreatment is needed to increase the sorption ability of the material.

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