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Research Article

Analysis of the potential of acid mine drainage generation from the neutralized coal mining tailings

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Abstract

Mining activities specifically Coal Mining have been long testified to be one of the major contributing factors to environmental crisis, with Acid Mine Drainage (AMD) as one of the leading indicators. The purpose of this study was to assess the potential of AMD generation from neutralized coal mining tailings. In order to achieve the ultimate objective of the study, analysis of chemical composition and mineral content of the tailings using XRF (X-Ray Fluorescence) and XRD (X-Ray Diffraction) respectively, lastly, a static analysis such as ABA (Acid Base Accounting) and TCLP (Toxic Characteristic Leaching Procedure) were also conducted. The results have shown that the studied tailing samples had relatively higher Acid Potential (19 kg $CaCO_3$/t to 20 kg $CaCO_3$/t) versus the Neutralizing Potential (NP) (14 kg $CaCO_3$/t to 18 kg $CaCO_3$/t). It was also found that the Net Neutralizing Potential Ratio (NNPR) is less than zero (-1.5 kg $CaCO_3$/t to -5.40 kg $CaCO_3$/t which indicates that the tailings have the potential to generate acid. The low concentration of CaO indicates acidic potential of the samples because CaO is a buffering mineral. Based on the results of the study, it was concluded that Mine Tailings has the potential to generate acid; therefore, the contamination to the nearby watercourses is extremely possible if necessary remedial actions should be considered.

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Introduction

Mining activities have been long reported to be one of the major contributing factors to environmental crisis. In which Acid Mine Drainage is one of the popular negative impact caused by mining activities. Akcil and Koldas (2006) have defined Acid Mine Drainage (AMD) as a form of exposure to sulphide minerals within the earth. This exposure may be brought about by several activities some of which are mining activities (abandoned polymetallic mines, mine workings, open pits, waste rocks piles and mill tailings), roadway constructions and other civil engineering activities (Akcil and Koldas, 2006). When sulphide minerals are exposed to the earth surface, they usually react with oxygen and water (Hodgson and Kranz, 1998). As a result, oxidation takes place; therefore, sulphuric acid is usually formed and then is able to enter water bodies (dams, river and lakes), and contamination begins (Akcil and Koldas, 2006).

Kabata-Pendias (1994) indicated that the mobility gradient of trace elements is influenced by climatic and soil factors. Heavy metals in soils control their bio-availability. Furthermore, Rosner (1999) contested that trace elements occur in different absorbing phases in soils and these phases can be investigated by performing special leaching tests such as sequential extraction tests. Indeed, the mobility of trace elements is an important factor for evaluating the short and long term environmental impacts associated with mine wastes (tailings). Hlavay et al. (2004) have reported that many single and sequential extraction methods have been developed in order to evaluate mobility, bio-availability and speciation of hazardous trace elements in soil, sediments and solid waste. Among these extraction methods is the TCLP (Toxic Characteristics Leaching Procedure) conducted to ascertain the leachability potential of hazardous and toxic chemicals from solid waste under typical environmental conditions. Based on the study by Soregaroli and Lawrence (1998), it is stated that the sustainability of long-term acid generation should be at least 0.3% sulphide and values below this can yield acidity but it is likely to be only for short-term significance. Samples with less than 0.3% sulphide-S are regarded as insufficient oxidisable sulphide-S to sustain acid generation.

Besides the short review documented above, it is well established that Acid Mine Drainage is a global threat for the mining industry and the surrounding environment. Nevertheless, the departure of this study is to argue that most studies on AMD are mostly looking into un-neutralized tailings to predict the impact which could be caused by the tailings. However, one can still want to understand the impact of neutralized tailing on the generation of AMD. It is believed that there is room enough to expose such impact since most studies are more concerned about tailings which are not neutralized.

Materials and Methods

This study involved collection of samples in which about 5 samples were collected and later combined to make two composite samples. The samples were therefore named TM1 and TM2; these samples were therefore considered for analysis in the total metal content using XRF and ICPMS was conducted, similar samples were also analysed for mineralogical composition (XRD), furthermore the potential to produce acid drainage and column leach were also analysed. The detailed methodology followed for the above mentioned techniques is denoted below.

Geochemical and mineralogical composition

As already highlighted above that chemical composition and mineralogy of the tailings/coal waste were analysed using X-Ray Florescence (XRF) for element composition (major and trace elements) and X-Ray Diffraction (XRD) to assess the mineralogy or crystallographic phases. The XRF analysis was performed using a PANalytical Epsilon 3 XL ED-XRF spectrometer, equipped with a 50 kV Ag-anode X-Ray tube, 6 filters, a helium purge facility and a high resolution silicon drift detector, calibrated using a number of international and national certified reference materials (CRMs). The samples were prepared by first drying the samples at 100°C for ~3 hours in order to determine loss of moisture content (H_2O-), followed by ashing of the sample at 1000°C until completely ashed, to determine the loss on ignition (LOI). The material was then prepared for XRD analysis using a back loading preparation method. It was analysed with a Malvern Panalytical Aeris diffractometer with PIXcel detector and fixed slits with Fe filtered Co-Kα radiation. The phases were identified using X'Pert Highscore plus software. The relative phase amounts (weight %) were estimated using the Rietveld method.

Geochemical static test (Acid Base Accounting test)

An acid producing potential of the tailings was evaluated using ABA. The neutralizing potential (NP) and acid producing potential (AP) of the samples were investigated using the modified Sobek Method; subsequently the net neutralising potential (NNP) also known as ABA, was determined using the same method (Sobek et al.,1978). The paste pH and EC tests of the materials were performed using the pH and EC electrodes, respectively.

Toxicity Characteristic Leaching Procedure (TCLP) test

The TCLP test was conducted using USEPA SW 864 method 1311 to define the mobility of organic and inorganic compounds present in mineral waste (USEPA, 1992). The extraction fluids used for extraction depended on the alkalinity of the waste material. An alkaline waste material such as the ash was leached out with solution 2 (made of glacial acetic acid (CH_3CH_2OOH) and distilled water). The tailings were leached with solution 1 (made of glacial acetic acid, distilled water and sodium hydroxide). After the selection of appropriate solutions, mobility of organic and inorganic compounds was assessed by agitating a 50.00 g sample in a 1 L extraction bottle filled with an appropriate solution using an end-to end rotating shaker at a rotation of 20 rpm for 18 hours at an optimum room temperature of 23ºC. At the end of 18 hours, the leachate was collected, filtered, preserved prior to ICP-MS and IC analysis.

Results and Discussions

Geochemistry and mineralogy of tailings waste

The XRF results have shown that SiO_2 is the dominant oxide within the samples followed by Al_2O_3 and Fe_2O_3, meanwhile the CaO, K_2O, MgO, SO_3 and TiO_2 were noted to occur in lesser amounts. The abundance of SiO_2 in both samples, TM1 and TM2, could be attributed to it being readily available in nature together with its resistance to weathering due to its hardness. The concentration of CaO controls the acidic potential of the tailings. In other words, when CaO is low, it means there is acidic potential in the material. In fact, Lapakko (1993) reported that Al_2O_3 and Fe_2O_3 both play a role in the release of acid and mobilization of metals and metalloids. The XRF results are clearly documented in Table 1. The tailings contained a high concentration of metals and metalloids in the following order: Ba, Sr, Rb, Cl, Cu, La, Ce, Th, Ni, Ga and Pb exceeding the concentration limits for soils according to (DEA, 2013) as documented in Table 2. Aucamp and Schalkwyk (2003) stated that elements such as Pb, Ni and Cu are highly mobile and in tailings material and their mobility is pH dependent.

Table 1. The XRF results of major elements (in wt.%) for tailings/coal waste.

Sample No	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	SO_3	LOI	Total
TM1	36.62	0.29	9.21	3.15	1.4	0.7	1.3	1.53	45.66	99.86
TM2	32.1	0.27	11.65	3.16	0.94	0.69	1.56	0.69	48.5	99.56

Table 2. The XRF results of minor elements (in wt.%) for tailings/coal waste.

Sample No	Ba	Sr	Rb	Cl	Cu	La	Ce	Th	Ni	Ga	Pb	Nd	U	Cd
TM1	1139	644	326	172	84.8	64.9	60.2	59.4	57.7	46.3	40	23.3	14.2	13.7
M2	1017	1017	624	174	103	73	28.4	60.9	35.9	48.4	56.2	31.7	13.5	14.3

Therefore, it was concluded that the neutralized tailing appears to have the ability to generate a high quantity of AMD if it is exposed to water. Mineralogical analysis by means of XRD on the samples displays a variation of both primary and secondary minerals. Primary minerals are considered to be ore and gangue minerals that were processed and deposited in an impoundment without any changes other than the reduction in grain size by comminution (Jambor, 1994). Secondary minerals are referred to those that have formed by processes that can lead to precipitation such as evaporation, oxidation, reduction, dilution, mixing and neutralization (Alpers et al., 1994). Secondary minerals include sulphate salts, as well as metal oxide, hydroxide, hydroxy sulphate and sulphide minerals. The tailings samples were consisting of the following primary minerals: SiO_2, Mica and Kaolinite and the secondary mineral Gypsum as indicated in both Figures 1 and 2. However, aluminum silicate minerals such as Kaolinite and Mica are considered to be potential acid neutralizers but in a low content and reaction rate compared to carbonate minerals such as calcite (Jambor, 2003). In this case, calcite has the lowest concentration in both samples as indicated in both Figures 1 and 2 which proves the acid producing potential of the tailings.

Figure 1. XRD results (in wt.%) for TM1 tailings waste.

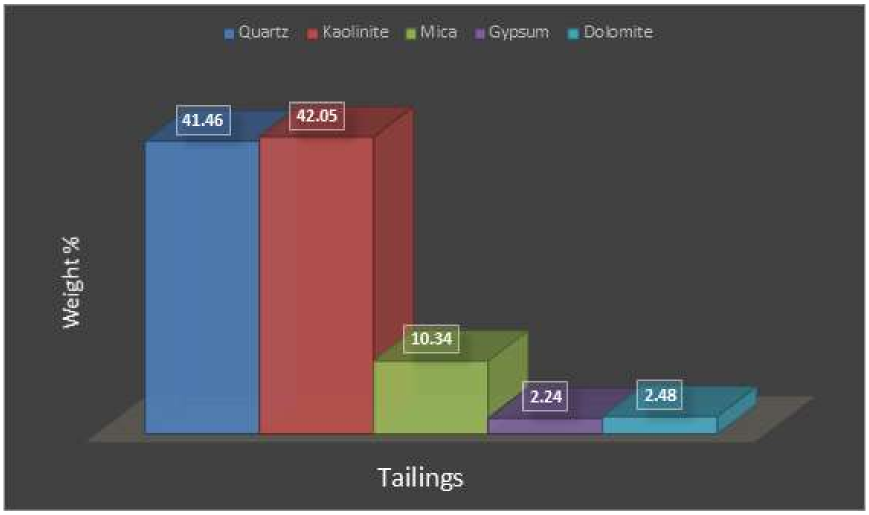

Figure 2. XRD results (in wt.%) for TM2 tailings waste.

Minerals such as Quartz have no potential for acid neutralization (Kwong,1993). The secondary minerals result from oxidation of sulphides and they precipitate during the evaporation of acidic, iron and sulphate rich water within mine waste material. Both samples have dolomite in their mineral assemblages. The presence of dolomite as a major acid consuming mineral is associated with the primary mineralization of host rocks (Department of Environmental Affairs (DEA), 2013). Furthermore, calcite was also found present in the mineral assemblage of the samples. Calcite is a buffering mineral and usually its presence means there is neutralization but in this case its concentration is very low which provide an indication of the acidic potential of the tailings.

Acid Base Accounting (ABA)

In Table 3, the Acid Base Accounting results are represented; these results are based on the Acid Potential (AP) and Neutralising Potential (NP) of both samples TM1 and TM2. TM1 and TM2 are characterised by high AP than NP and their Net Potential Ratio (NPR) of less than 1(NPR<1) which indicates the acid producing potential of the samples. Their AP was found to range between 19 kg $CaCO_3$/t to 20 kg $CaCO_3$/t whereas NP ranges from 14 kg $CaCO_3$/t to 18 kg $CaCO_3$/t. Based on the geochemical results, the samples contain high amounts of Sulphur in a range of 0.5-0.6 wt% which indicates the presence of pyrite as a primary acid producing mineral. Both samples were classified as potentially acid forming.

In this regards, one can deduce that both samples had high Acid Potential than Neutralising Potential, therefore, this type of tailings has a high possibility to generate AMD across the water bodies. Despite the Neutralization process took place, the samples still present a high potential of generating acidic solutions, therefore this gives an impression that although coal mine tailings could be neutralized, but further care has to be considered to ensure that the surrounding environment is safe.

Table 3. The ABA results of samples TM1 and TM2 (kg $CaCO_3$/t) for tailings dump.

Acid Base Accounting	Sample Identification	
	TM1	TM2
Paste pH	7.3	7.3
Total Sulphur %	0.61	0.63
Acid Potential (AP)(kg/t)	19	20
Neutralising Potential (NP)	18	14
Net Neutralising Potential(NNP)	-1.57	-5.40
Neutralising Potential Ratio(NPR)(NP:AP)	0.918	0.726

Toxicity Characteristic Leaching Procedure (TCLP)

The Toxicity Characteristic Leaching Procedure (TCLP) was applied in order to determine the leacheability and mobility of trace metals and metalloids from the coal tailings. Samples were analysed, the TCLP results have shown that the most leachable and mobile trace elements are Ca, Mg, Na, K, Sr, Si, Ti and Mn. The most leachable and mobile trace elements with the highest concentration are: Ca, Mg and Na (Figure 3). The least leachable trace elements with the lowest concentration are K, Sr, Si, Ti and Mn (Figure 4). The results are useful for the prediction of contamination or buffering potential of the tailings. There were no heavy metals detected from the leachates; therefore, it was concluded that the tailing has high contamination with limited buffering potential presented by Calcium, Magnesium and Sodium as a result of liming of the tailing.

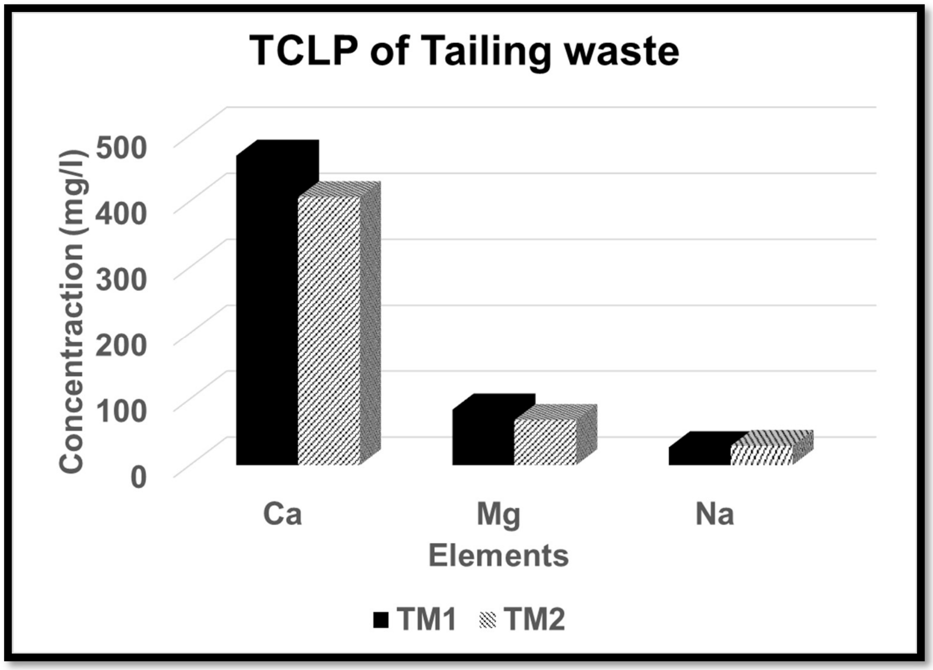

Figure 3. Leaching trend in TCLP for elements exhibiting high concentrations in the effluent (leachate).

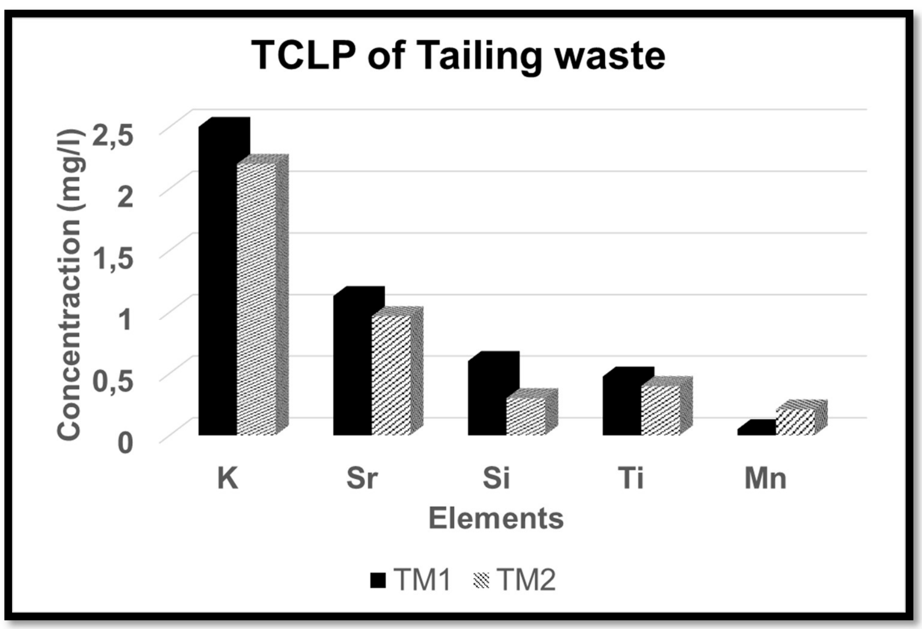

Figure 4. Leaching trend in TCLP for elements exhibiting low concentrations in the effluent (leachate).

Conclusion

Based on the results and discussions of the study, it is concluded that the studied neutralized coal mining tailings have high potential of generating Acid Mine Drainage. It has been documented in the study that the studied samples still contain large quantity of Acid Mine Drainage mineral indicators and it is expected that when the tailing interact with water AMD during heavy rainfall generation of AMD is expected. It is recommended that remedial action could be initiated to protect the environment surrounding the tailings.

Acknowledgements

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