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Effect of Particle Size on Leachate Formation Characteristics from Gold Mine Waste Rocks: At Source Acid Mine Drainage Management in Tanzania

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ABSTRACT: Waste rocks from gold mining operations represents a significant environmental burden and impairs sustainable environmental management in developing countries. This study focused on understanding the leachate properties of different particle sizes (>10mm, 20mm, 30mm and 50mm) from the waste rock dump (WRD) - GPAF in the 30 liters containers to represent waste rocks by using quick static testing to determine a more rational design basis for material storage and management. This study found that small particle sizes of waste rocks with <10 mm showed a strong leaching with a low pH of 3.5, while large particle sizes of 50 mm showed a high pH of 6.5. Metal leaching of small particle sizes had a higher concentration of Manganese, Zinc and Iron than large particle size. Similarly, sulphate concentration from leachate of small particle size of waste rocks had higher levels than large particle size. In addition, this study also demonstrated that the majority of dissolved metals (Mn, Zn and Fe) leached higher in the low pH (3.5) leachate. This study recommended that great emphasis be taken on the separation of small particles from large particle sizes of mine waste rocks during and after mining operations to reduce the risk of metal leaching and the possibility of acid mine drainage (AMD) formation and pollute surface and groundwater.

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Mine waste rock management is a global concern as wastes such as AMD, leachate from mining waste or materials have significant environmental impacts (Vivoda and Fulcher, 2017). Accurate assessment of mine wastes is critical for regulatory decisions and site prioritization, as most mine sites have the potential for ongoing environmental impacts due to the lack of individual tests that can predict potential mine drainage from mine wastes (MEND, 1991). Accurate assessment of metal leaching from mining waste dumps is of major importance for environmental degradation (Hageman and Briggs, 2000). One of the environmental problems associated with mining operations today is the increasing presence of metals in the environment (Paktunc, 1999). Mine drainage from sulphurous waste rock dumps remains a significant environmental problem in parts and worldwide (Price, 2003). However, the geochemical composition and flow rate of mine drainage from a waste rock material depends on various factors such as local climate, mineralogical composition and deposit structure. Placek and Blowes (2003) provide information and data on the chemical composition of various mine drainage waters. The short- and long-term behavior of mining waste can be determined by geochemical laboratory testing, including static testing and long-term kinetic and geochemical modeling (Nordstrom and Nicholson, 2017). Static test is a quick and inexpensive way to determine if specific geological units have acid production potential and can serve as good indicators of theoretical acid production potential. However, kinetic tests can be used to describe reaction rates over a given period of time for certain environmental conditions (Robertson

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and Broughton, 1992). When examining the properties of mining waste rock, the particle size of mine rock materials is one of the important parameters that can affect the materials' ability to leach out or generate acid or alkalinity and other components in the environment (Lapakko *et al*., 1998).

The use of very fine reactive sulphide materials can increase the potential for acidification trapped in the mine waste materials; large particle materials cannot be subjected to easy oxidation (Lapakko*et al*., 1998). Likewise, increasing the distance between reactive particles and neutralizing particles in fine-grained materials can inhibit the development of low pH, which is always present in large stocks of material (Robertson and Broughton, 1992). In addition, small diameter particle sizes of mine waste rocks can affect pore size and permeability, which can affect the quantity of liquid in the pore spaces of grainy materials and the length of time this amount is retained in the material. Once mine drainage occurs, managing the drainage or release becomes more difficult and expensive, and therefore accurate characterization of mine waste rock can be an important method for mine drainage management (Ferguson and Erickson 1988). The objective of this study is to monitor the effects of particle size on leachate formation characteristics from gold mine waste rocks: At source acid mine drainage management in Tanzania.

MATERIALS AND METHODS

Leachate formation processes and characteristics from waste rock source materials: In this section of the study, the processes and characteristics of leachate formation from different leachate sources (waste rock materials) were examined in order to gain a better understanding of the methods or tools used to characterize mine tailings rocks of leachate formation from tailings rock materials. This study included the collection of waste rock samples and the experimental design of waste rock leaching. The sulphide wastes are waste rocks in solid form which, upon contact with water and air, have the potential to produce acid mine drainage.

Waste rocks sample collection: Overburden rock materials grading 0.3% sulphide were collected from the North Mara Gold PAF with high potential to generate acid mine drainage and were placed between 2010 and 2017. Mine waste rock samples were collected using a method described by Moyle and Causey (2001). Waste rock samples were crushed into powder by a pulverizer, and then the sample was sieved to pass a fraction of 0.4 mm in size. The samples were crushed into small sizes to maximize contact time and increase the surface area of the waste rock material. The smaller materials are generally the most reactive and also control or provide for water leaching behavior of the waste materials (Smith *et al*., 2000). All waste rock samples were crushed and sieved to various particle sizes (<10mm, 20mm, 30mm and 50mm).

Design setup of a waste rock leaching batch experiment: Waste rock samples were categorized into <10mm, 20mm, 30mm and 50mm. This study method was adopted from Price and Kowing (1997) who indicated that the field leach test is designed such that the majority of the chemically reactive (acid/metal production potential) of the mine waste rock appears as very soluble components in mining fine (<2mm) particle size of the sample. The purpose of reducing the waste rock feedstock size is to maximize worst case leaching from various particle sizes. A 30 liter container with a diameter of 0.5 m and a height of 0.3 m was used. The weight of the waste rock stored in the container was 10 kg.

Crushed and screened waste rock materials mixed with deionized water in a 1:2 (w/v) ratio as described by Sobek *et al.,* (1976). The batch leach experiment of different sized waste rock source materials (<10mm, 20mm, 30mm and 50mm) were carried out in the environmental SEST hall at Ardhi University. The containers were cut and opened at the top to allow easy infiltration of oxygen into the mixture of waste rock (feedstock) and water. Each time the containers were nearly dry, deionized water was added to replace the evaporated water.

Leachate water sample analysis: Leachate formed from each bucket was sampled and the physical and chemical parameters were analyzed at Ardhi University Environmental Engineering Laboratory. The physical parameters analyzed include pH and EC while the chemical parameters are Mn, Zn and Fe.

RESULTS AND DISCUSSION

Leachate pH and Electrical Conductivity (EC) characteristics in batch experiment: The results of the characterization of waste rock leachate from waste rock materials based on pH and EC are presented in Table 1 and Figure 2. In general, smaller particle size waste rock materials (< 10 mm) exhibited low pH compared to large particle sizes (> 50 mm). A similar observation was observed when EC behaved with small particle size. The difference between small particle size and large particle size is higher as shown in Table 1. The results showed that the pH in Figure 1 was high in the first few days, but from 5th to 56th day the pH decreased very rapidly down to 3.5 at GPAF<10 mm, at GPAF 20 mm 5.2, while GPAF

30mm was 5.9 and GPAF 50mm was 6.1. A similar trend was also observed in Figure 2, where EC increased from day 7 to day 56. The trend showed that at day 56, GPAF < 10 mm was 2990 s/cm, while GPAF 50 mm was 1025 s/cm.

Table 1: Leachate Characteristic Results from Batch Experiment on Different Particle-size Fractions of Mine–waste Materials

Particle -size	pH	EC (µs/cm)
GPAF-WRD		
<10mm	3.5	3012
20mm	5.2	1760
30mm	5.9	1580
50mm	6.2	1032

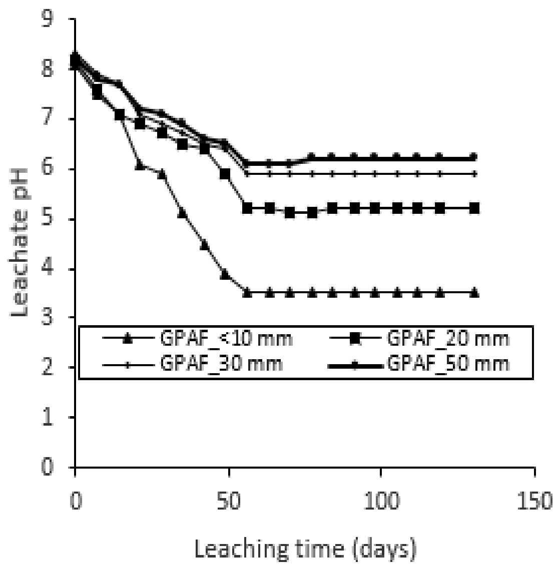

Fig1: Variation of pH in leachate formation from GPAF waste rock dump in batch experiment

pH is considered an important parameter for monitoring the generation and rate of the AMD formation process (Erguler, 2014). This study analyzed the pH of leachate formed from batch experiments with different particle sizes. Based on this study (Table 1), it is evident that particles < 10 mm in size have the ability to produce AMD with pH of 3.5. Sapsford *et al*., (2008) suggested that a pH of 4.5 must be taken as the cut-off point to decide that leachate formation represents potential AMD. This study has shown that since the first days of the batch experiment, the pH has decreased and the EC has also increased. The results are also supported by other researchers (Robertson and Broughton, 1992) who reported that other parameters such as the EC increase as pH decreases.

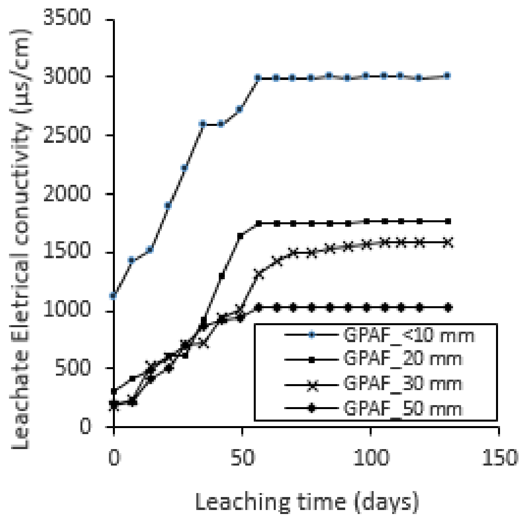

Fig2: Variation of electrical conductivity in leachate from GPAF waste rock dump in batch experiment

However, the study conducted by Erguler (2014) found a pH drop of up to 4.5 but contradicts this study which observed that the pH reached 3.5 after 130 days of the experiment. The pH of the leachate decreased from the first days to the 56th day, from then onwards remained unchanged (Figure 1). This observation is consistent with (Erguler, 2014) who reported that pH variation was unstable over time and fluctuated significantly due to the ongoing oxidation and neutralization process. The leachate pH for small particles is significantly low, suggesting that the materials have the potential to produce AMD compared to large particles. Robertson and Broughton (1992) concluded that the rate of sulfide oxidation is directly proportional to the surface area of the sulfide exposed to oxidation. Lapakko*et al*., (2006) stated that the pH value decreases with decreasing particle size. Therefore, the influence of particle size can be complicated and coarse particle sizes are typically less reactive (Parbhakar-Fox *et al*., 2013). This study found that in order to reduce contaminated water from waste rock materials, it is important to separate the large particle size waste rock from the smaller ones, simply because the smallest particle size reacts strongly when in contact with air and water and this can increase contaminated leachate.

Metal leaching characteristics from waste rock source materials: Studying metal leaching from mine waste rocks is one way to predict AMD potential (Erguler, 2014). The results of the batch experiment characterizing mine waste rock for leaching of metals (Mn, Zn and Fe) are shown in Figure 3, Figure 4 and Figure 5. In general, the final results showed that after waste rock materials were leached for 130 days, GPAF<10 mm showed a higher initial zinc increase from day 7 to 130, with the zinc concentration in the leachate reaching 3.8 mg/L (Figure 3). In Figure 4, the manganese concentration in the leachate was 12 mg/L and the iron concentration was 3.1 mg/L. Therefore, the results indicate that the leachate concentration increased similarly with increasing number of days, but the trend remained unchanged since day 98 (Figures 3.4 and 5). In addition, the results for large particle size waste rock materials with a GPAF of 50mm indicated that the leachate concentration of metal leaching was not significant. In addition, as can be seen in Table 2, as the pH decreases, more metals are dissolved and leached. Erguler (2014) reported that as the pH drops to 4.0, the metal leachate concentration increases rapidly.

Table 2: Metal Leachate Characteristic from Batch Experiment on Different Particle-sizes

Particle -Size Fractions / **GPAF-WRD**	pH	Mn (mg/L)	Zn (mg/L)	Fe (mg/L)
<10mm	3.5	12	3.8	3.1
20mm	5.2	5	1.2	0.8
30mm	5.9	3	0.01	0.4
50mm	6.2	1.7	0.005	0.1

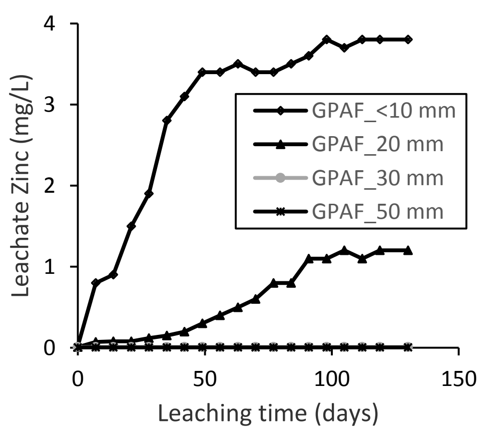

Fig3: Variation of zinc in leachate from GPAF waste rock dump in batch experiment

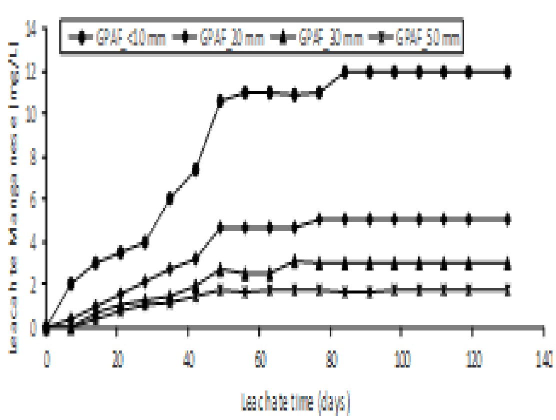

Fig4: Variation of manganese in leachate from GPAF waste rock dump in batch experiment

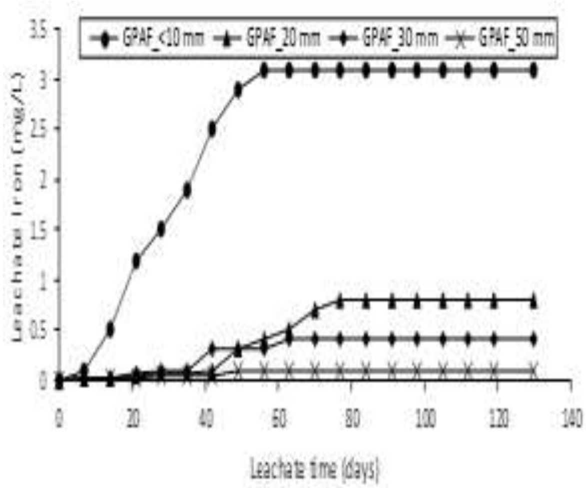

Fig5: Variation of iron in leachate from GPAF waste rock dump in batch experiment

In this study as indicated in Table 2, concentration of Mn was higher compared to other metals. Other study by (Kwong, 1993) suggested that some metals such as Co and Ni increases resistance of leachate to oxidation. In addition, this study found that small waste rock particles showed strong responses to metal leach formation. For example, GPAF materials < 10 mm in size experience higher metal leaching compared to large particles such as 50 mm in GPAF. In the mining industry, when studying metal leaching and acidification, it is crucial to consider characterizing the possible sources of metal leaching (Al-Abed *et al.*, 2006; Hammarstorm and Smith, 2002). Small particle sizes are always the most critical as they are highly reactive and control the leaching behavior of bulk waste materials. A <2mm particle size separation analysis and assessment of the weathering effects of waste rock dumps is essential as all physically available mineral grain size is in the <2mm particle size. Therefore, the collection of particles < 2 mm in size would represent a worst-case scenario for mine waste rock characterization (Price and Kwong, 1997). In addition, it is shown in Table 2 that GPAF were sulphide waste rock materials and had the potential to generate AMD as it is clearly shown that at mine waste rock with particle size <10mm there is reaction and evidence of strong metal leaching . This also allows the conclusion that metal leaching behavior is directly proportional to particle size fractions. This conclusion is also shared by Zhang *et al.*, (2019) reported that the smaller the particle size, the faster the dissolution rate of metals and the higher the concentration of the leach solution.

Conclusion: The particle size of the waste rock can affect the characteristics of leachate formation. Small particle sizes had a low pH compared to large particle sizes. The metal leaching concentration was in the following order of particle size: 10 mm > 20 mm > 30 mm > 50 mm. This study found that leachate with small particle sizes and low pH had higher concentrations of dissolved metals (Mn, Zn and Fe). To reduce potential of AMD formation, small particle sizes should be part of mining waste rock management.

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