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The effect of particle size on acid mine drainage generation: Kinetic column tests

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ABSTRACT

The rate of acid mine drainage (AMD) generation is directly proportional to the surface area and so to the particle size distribution of acid-forming minerals exposed to oxidation. Materials in various particle sizes are subject to weathering processes at field condition; however, the particle size dependent oxidation rate has not been investigated for understanding entire geochemical behavior at a mining site. Therefore, a comprehensive research program was aimed to investigate the effect of particle size on pH variation and acid mine drainage generation using kinetic column tests, and then to find convenient methodologies for upscaling laboratory-based results to the field condition. For this purpose, ore samples collected from Murgul Damar open-pit mining were grinded in three different particle size distributions that are coarse (minus 22.5 mm), medium (minus 3.35 mm) and fine (minus 0.625 mm) sizes, 34 columns were designed in different dimensions for kinetic column tests. It was found that the cumulative concentration of the many constituents measured from medium particles (minus 3.35 mm) are higher than coarser samples due to decreasing specific surface area with increasing particle size. Similarly, because of decreasing of hydraulic conductivity with increasing the fine content, the cumulative concentration of constituents measured from medium particles (minus 3.35 mm) are also higher than finer particles (minus 0.625 mm). Based on statistical and analytical analyses of the results of kinetic column tests, the time required to initiate acid formation at field condition varied between 489 and 1002 days depending on particle size distribution. In addition, considering the effect of particle size and the results of related statistical analysis, main oxidation (SO_4^{2-}) and neutralization (Ca^{2+}, Mg^{2+}, Mn^{2+} etc.) products were also successfully upscaled to the field condition.

1. Introduction

There must be an exposure of acid-forming mineral (e.g., pyrite, chalcopyrite etc.) to atmospheric conditions for acid mine drainage (AMD) generation. The variation in concentration of contaminants caused by AMD formation depends on specific surface area of these minerals exposed to oxidation processes. Therefore, due to close dependency between specific surface area and particle size, the rate of AMD generation relates entirely on particle size distribution after blasting and crushing which provided automatically as partially or fully exposed particles during extraction of valuable ore minerals. As given in Fig. 1, the comminution and so liberation of acid-forming minerals (e.g., sulfur-bearing minerals) is important for increasing specific surface area subjected to oxidation process and thus increase its potential for AMD generation. In the case of having suitable permeability condition, because of having more specific surface, a material consisting of finer particles (Fig. 1b) may participate in the AMD formation more quickly than coarser particles (Fig. 1a).

AMD is a time-dependent phenomenon and its generation rate is controlled by several factors such as pH, mineralogical composition, climatic condition and particle size distribution. Acid-base accounting (ABA) is static test does not take into account the effect of many of these factors, particularly the rate and evolution of oxidation and neutralization processes. Therefore, in order to increase reliability of evaluation related to AMD generation, kinetic tests were mainly performed previously (Lawrence and Marchant, 1991; Morin and Hutt, 1997; Sapsford et al., 2009; Parbhakar-Fox et al., 2011, 2013) to simulate actual field oxidation and neutralization processes at laboratory scale. Bradham and Caruccio (1990) stated that the kinetic column test is considered to be more representative of actual field conditions. Various particle size ranges were recommended by different protocols for determination AMD generation from kinetic tests at laboratory condition. According to AMIRA P387A (2002) handbook, kinetic tests should be performed on

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samples having particle size of minus 4 mm without any lower limit. The particle size recommended by ASTM D5744-96 (ASTM, 2000) and MN-DNR should be 100% passing 6.3 mm and 10 cm (Lapakko, 2003), respectively. Conventional humidity cell testing requires samples crushing to minus 2 mm (Robertson and Broughton, 1992). Thus, researchers carried out kinetic test by using different particle size. Bradham and Caruccio (1990) reported that a particle size larger than 0.5 cm is more representative for particle size distribution of field conditions. Performing kinetic tests on a range of size fractions can improve the understanding of mine waste weathering characteristics, and the accuracy of subsequent geochemical modeling (Alpers and Nordstrom, 1999; Maest and Kuipers, 2005; Parbhakar-Fox et al., 2013). Despite of samples having wide range of particle size distribution were used previously for assessment AMD generation, there are differences between laboratory and field kinetic behavior of the oxidation of acid forming minerals. This situation emphasize further requirement to develop the reliable upscaling methodology for estimation the rate of AMD generation and field concentration of contaminant.

Although, it is well known that materials having various particle size distributions are subject to weathering processes at actual field condition, the effect of particle size on the degree of oxidation of sulfide phases has not been investigated for understanding the entire geochemical behavior at a mining site. Robertson and Broughton (1992) stated that the differences between laboratory and field kinetic behavior must be understood and appropriate corrections applied when extrapolating laboratory results to field estimate. Considering the limitation related to simulating actual particle size at laboratory scale and recommendation from previous studies, a research program was initiated to understand particle size dependent AMD generation at laboratory condition, the effect of particle size on the pH evolution and rate of AMD, the relationships between particle size and concentration of main oxidation and neutralization products in AMD, and finally to find convenient upscale strategies for extrapolating laboratory results to actual field scale. For this purpose, a comprehensive field investigation was performed at Murgul Damar open-pit mining site to determine particle size of materials representing actual field breakdown condition after mining operation and extract adequate samples to be used for kinetic column tests in the laboratory. The representative particle size distribution curves belong to Murgul mining site were found in wide ranges due to mining operations such as blasting, excavation, and breakdown caused by heavy equipment. Samples collected from this mining site were crushed into three different particle size distributions, which are coarse (minus 22.5 mm), medium (minus 3.35 mm) and fine (minus 0.625 mm) size specimens. Thirty-four columns designed in different dimensions were used for kinetic column tests. Statistical and analytical analyses of kinetic column tests reveal very significant conclusions for predicting the effect of particle size on the amount of soluble metals, lag time, main oxidation (SO_4^{2-}) and neutralization (Ca^{2+}, Mg^{2+}, Mn^{2+} etc.) products and so upscaling these conclusion to the field condition.

2. Materials and methods

To understand the physical and chemical mechanism behind the effect of particle size on the rate of AMD generation and so related concentration of contaminants, a field investigation was performed to determine particle size distribution curves of broken materials after mining operation and collect relevant samples to simulate AMD generation based on kinetic principles to represent actual field condition. The details in associated with field investigations, appropriate sampling, climatic condition of sampling site, and methodologies in conjunction with understanding the effect of particle size on acid mine drainage are summarized below.

2.1. Materials

Murgul open pit copper mining site that located in Artvin (Turkey) was chosen study area for achieving the objectives of this research. Oxidation processes of a region and so the AMD formations are specified by effective climatic conditions. Despite of warm and rainy climate of the coastal areas of the North Eastern Black Sea, the research site is defined by cold weather condition and snow covered during winter season, rainy and cool climate during spring and summer. Based on fifty-year meteorological records, it was found that the annual rainfall, humidity and temperature of sampling site are approximately 70.9 cm, 65% and 12 °C, respectively. According to conceptual model proposed by Peltier (1950), moderate chemical weathering processes control AMD formation of this site. Samples to be used for the simulation of AMD generation at laboratory condition were taken from Upper Cretaceous aged Murgul Formation. In order to start AMD formation from its beginning stage and monitor initial oxidation processes, fresh ore samples having a mass of 300 kg were taken from newly excavated outcrops.

2.2. Geomechnical properties of discontinuities and in-situ particle size distributions of break down materials

Some of physical properties of discontinuities within rock masses such as frequency, orientation, spacing, persistence, weathering and roughness are significant controlling factors on

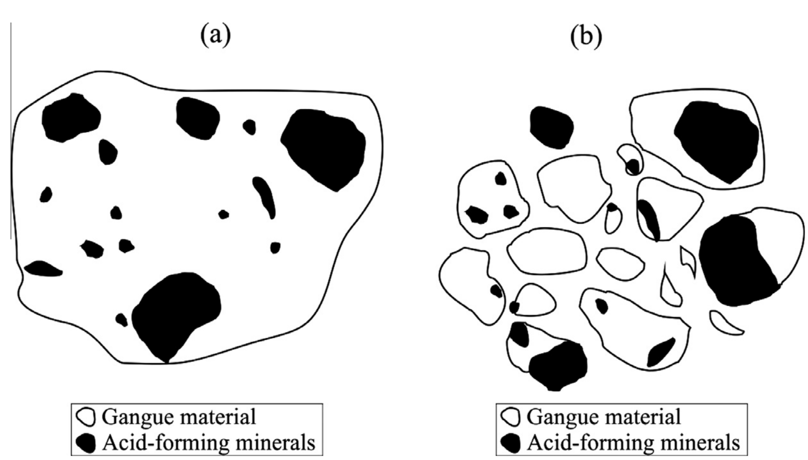

Fig. 1. Illustration of the importance of particle size on AMD generation due to differential degrees of liberation.