CHEMICAL ENGINEERING TRANSACTIONS

VOL. 100, 2023

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Sauro Pierucci, Flavio Manenti
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ISBN 979-12-81206-03-8; **ISSN** 2283-9216

DOI: 10.3303/CET23100096

Simulation of Weathering in Mine Waste Rock for Acid Drainage Control Using a Wet Column

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The negative impacts of mining operations are generally intensified by the lack of preventive measures in the management of mining waste, one of them being the disposal of waste rock that generates drainage depending on its geology, mineralogical composition, geochemistry and solubility of the metals present. The objective of the research was to simulate the weathering of waste rock from mining activities in a wet column under controlled laboratory conditions. The physicochemical parameters were evaluated for 20 weeks. Results were obtained on leachate acidity as one of the main parameters, the pH was found to be between 6.0 and 7.5; this was due to the presence of carbonates as a neutralizer. The results allow taking measures to plan efficient waste management throughout the mining operation process, especially at mine closure, contributing to the control of negative impact.

1. Introduction

There are a large number of mining environmental liabilities related to abandoned waste dumps and others with an eminent danger of negative impacts from contaminating leachates, with approximately 6,903 mining liabilities in Peru (MINAM, 2022). Acid drainage often has high acidity, dissolved heavy metals and sulfates and is produced when these waste dumps are exposed to water and oxygen in the air; acid mine drainage release occurs mostly in sulfur-rich waste dumps (Ryu et al., 2019), so determining the acidity level of mine drainage will allow us to find the most appropriate method for its treatment and have the quality level within the values that do not affect the environment given the danger it represents due to its content of highly toxic elements such as heavy metals that could spread due to their high mobility and accumulation in the face of pH variations (Sarmiento, 2007); It will also serve to search for methods to recover metals from these drains, if possible, as proposed by Zamora and Meza (2022), and to recover water by low-pressure nanofiltration methods and sequential adsorption of acid mine drainage (Fonseka, 2022).

Research has been conducted to prevent acid mine drainage (AMD) in some cases using sulfur-containing rocks to be used as a dry cover layer (Matsumoto et al., 2015), in other cases treating drainage by ultra-low pressure reverse osmosis and nanofiltration processes tested in a copper mine (Zhong et al., 2007), in other research NaOH has been used to neutralize these drainages (Umi et al., 2020); biological treatment is a viable alternative for acid leachates when landfills are less than 5 years old (Kamal et al., 2022), or the use of the phytoremediation technique (Tejeda-Benites et al.,2022; Ayme E. et al., 2022). The type of mines generating the drainages, such as coal waste dumps, should also be taken into account (Matsumoto, et al., 2016).

The objective of the study was to determine the level of acidity by simulating the weathering of a sample of mine waste in a wet column in order to obtain information on the acid drainage that can be generated and to find a solution for the management of these hazardous wastes, that are generally abandoned because they are sometimes considered non-offensive and are seen as simply exposed rocks.

Paper Received: 18 January 2023; Revised: 16 April 2023; Accepted: 12 May 2023
Please cite this article as: Mendoza L.F., Acosta Suasnabar E., Sandoval A.N., Castaneda-Olivera C.A., Suca-Apaza G.R., Benites-Alfaro E., 2023, Simulation of Weathering in Mine Waste Rock for Acid Drainage Control Using a Wet Column, Chemical Engineering Transactions, 100, 571-576 DOI:10.3303/CET23100096

2. Methodology

2.1 Sample collection

The sample of waste from the mining activity was taken in the vicinity of a mining company and was dried in the environment under aerated conditions for 96 hours. See Figure 1. Then, tests of granulometric distribution and permeability (permeability coefficient) were carried out.

Figure 1: Sample of mine waste material

2.2 Characterization of mine waste samples

The waste rock sample was subjected to static tests to determine the geochemical characteristics and potential for acid and/or alkaline drainage generation. This is fundamental to establish the level of acidity; a net acidity potential will be present when the wastes exceed the neutralization potential through the course of weathering. The pH, sulfides were also determined to find the net generation of acidity (GNA) with Eq. (1), the acid potential (PA) was determined with Eq. (2), the neutralization potential (PN) with Eq. (3) and the net neutralization potential (PNN) with Eq. (4).

$$\mathrm{GNA} = \mathrm{F} * \mathrm{V} * \mathrm{M} * \mathrm{W} \tag{1}$$

Where: GNA = Kg H_2SO_4/Tm; F= Conversion factor (49); V= Volume of NaOH; M = NaOH molarity;
W = sample weight

$$\mathrm{PA} = \%\ \mathrm{sulfur} * \mathrm{factor} \tag{2}$$

Where: PA = kg of $CaCO_3$/Tm; Factor = 31.25

$$\mathrm{PN} = \frac{(\mathrm{VHCl} - \mathrm{VNaOH}) * 0.5N * Vvolumen\ HCl}{Wg} \tag{3}$$

Where: V_{HCl}: The volume of hydrochloric acid; N: Normality of hydrochloric acid; V_{NaOH}: Volume of sodium hydroxide; W_g: Weight of the sample in grams

$$PNN = PN - PA \tag{4}$$

Where: PNN = kg of $CaCO_3$/Tm; PN: Neutralization potential; PA: Acidity potential

2.3 Controlled simulation test of acid drainage in a column

A wet column of dimensions 1.50 m long and 0.254 m in diameter was built in order to simulate a rainfall with 4 liters of water per day and subjecting the mining waste sample to weathering for 20 weeks, in order to observe the phenomena and evidence of reactions that may occur; that is, the waste was subjected to accelerated weathering under controlled laboratory conditions, the geochemical process was determined and then the type of leached drainage generated every 24 hours was identified. See Figure 2.

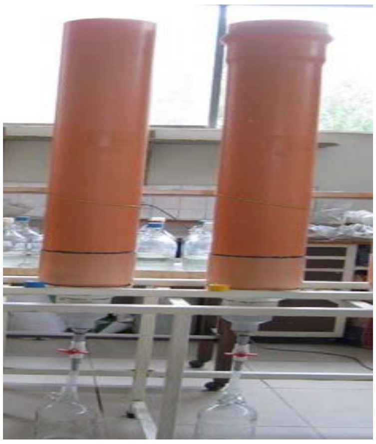

Figure 2: Wet columns

3. Results and discussion

3.1 Particle-size distribution of mine waste rock

With the granulometric analysis based on the analysis curve and the uniformity and curvature coefficients from the opening diameters where 10, 30 and 60 % of the sample passes (Table 1), it was found that the mining residue had a sandy-gravelly structural conformation.

Table 1: Granulometric analysis of the waste rock

Mesh	Opening (mm)	Retained (%)	Accumulated (%)	
			Retained	Pass
10”	250	0	0	100
5”	125	5	55	45
2”	50	2	20	25
1”	25	1.6	16	9
1/2”	12	0.5	5	4
No. 80	0.18	0.3	3	1
Bottom	-	0.1	1	0

The permeability coefficient was also found, which was equal to 4.0 x 10^{-5} m/s, and this was considered in the design of the column to obtain optimal results. This coefficient allows calculating the water flow capacity through the pores of the soil according to its texture, and is used as a measure of rejection of the flow offered by the soil (Whitlow, 2000).

3.2 Static analysis of waste rock sample

The sample reduced to 60 % mesh was determined the percentage of sulfide, as well as the pH (see Table 2). Taking into account the standard method US EPA 600/2.78-054 (1996) and with equations (2), (3), and (4), the net neutralization potential (PNN) was found. According to the norm of the Peruvian Ministry of Energy and Mines, PNN values greater than 20 would not generate acid drainage, which complies with the value found; but the statement is not definitive because the geochemistry of the waste rock must also be analyzed, the latter is established with the test in the wet column.

Table 2: Static testing of the waste rock

Sample	pH	% S	PN	PA	PNN	PN/PA
Waste rock	7.3	1.65	89.37	52.81	32.56	1.69

Note:
If: PNN > +20; the sample does not generate acid drainage
If: PNN < -20; sample generates acid drainage
If: -20 < PNN < +20, the sample has uncertain behavior

3.3 Mineralogical composition of the waste mining rock

It was determined by microscopic observation and x-ray diffractometry that the mining waste had the composition shown in Table 3. Fragments of propylitized volcanic rocks were found with phenocrysts of plagioclase, carbonates, rhodonite, and the dissemination of sulfides, with abundant silicates.

It can be seen that the chemical element of greater presence in the cuttings are otoclases, plagioclase, quartz, and chlorite, not less important is the presence of pyrite as a sulfide compound.

Table 3: Chemical composition of mine waste

Mineral	Formula	Amount (%)	Mineral	Formula	Amount (%)
Quartz	SiO_2	13.90	sphalerite	ZnS	0.16
calcite	$CaCO_3$	5.20	Galena	PbS	0.01
orthoclase	$KAlSi_3O_8$	34.10	hematite	Fe_2O_3	0.30
plagioclase	$(Na, Ca)(Si, Al)_4O_6$	22.60	kaolinite	$Al_2SiO_5(OH)_4$	1.80
Muscovite	$KAl_2Si_3AlO_{10}(OH)_2$	5.30	pyrolusite	MnO_2	0.16
Biotite	$KMg_3(Si_3Al)O_{10}(OH)_2$	1.10	rhodochrosite	$MnCO_3$	0.21
Pyrite	FeS_2	2.97	Rhodonite	$MnSiO_3$	0.71
chalcopyrite	$CuFeS_2$	0.02			

3.4 Geochemical composition of mine waste rock

By means of analytical spectrographic methods, atomic absorption spectrometry and classical methods, the chemical composition was determined as shown in Table 4.

Table 4: Geochemical composition of the mine waste rock

Chemical compound	Amount	Chemical compound	Amount
% SiO_2	55.50	% S	1.65
% Al_2O_3	19.71	% Cu	0.01
% Fe_2O_3	8.09	% Pb	0.01
% CaO	3.27	% Zn	0.11
% MgO	0.93	% As	0.0018
% Na_2O	2.50	% Cd	0.001
% K_2O	3.95	Hg (ppm)	0.23
% MnO	0.65	Ag (ppm)	10
% TiO_2	0.98	Au (ppm)	0.036
% CO_2	2.29		

3.5 Physicochemical parameters of the waste rock in the wet column

The results of the simulation of the weathering of the mine waste in wet columns were carried out for 20 weeks, during which time the leachate generated was monitored weekly, evaluating the physicochemical parameters, the results of which are shown in Table 5.

The pH remained in the range of 6.0 to 7.5 therefore no acid drainage was generated, this was due to the sufficient neutralizing material that existed in the waste rock (carbonates), a study indicates that by neutralizing this type of leachate, good removal of heavy metals from an acid mine drainage was obtained (Jimenez, 2017). Sulfates reached high values at the beginning and then decreased with a tendency to decrease, but with increases and decreases. Conductivity had a reduction throughout the test. This is due to the oxidation-reduction reactions that take place in the process.

Table 5: Physicochemical parameters of wet column leachate

Weeks	Volume extracted (L)	pH	Conductivity (µS/cm)	Alkalinity (mgCaCO$_3$/L)	Redox potential (mV)	Sulfates (mg/L)	Cu (mg/L)
1	0.950	6.6	1262	2.0	246	393.9	0.010
2	1.100	6.5	1509	1.6	238	406.9	0.003
3	1.350	6.7	1323	20.0	265	313.8	0.005
4	1.500	6.8	1201	0.4	244	161.4	0.009
5	1.300	7.0	950	17.6	232	242.9	0.002
6	1.250	7.0	393	22.0	231	115.6	0.002
7	0.800	6.0	362	27.0	225	7.5	0.002
8	0.750	6.5	304	29.0	218	35.1	0.003
9	1.150	6.9	335	32.0	209	47.7	0.002
10	0.900	6.7	354	28.4	236	45.0	0.012
11	1.450	7.0	346	28.0	237	77.2	0.002
12	1.100	7.0	366	27.0	245	64.7	0.001
13	1.000	7.0	685	30.0	220	85.7	0.002
14	1.250	6.8	685	20.0	234	75.1	0.003
15	1.300	6.4	632	27.4	214	66.1	0.003
16	1.400	7.4	299	29.0	210	88.5	0.002
17	1.350	7.3	328	29.0	225	114.1	0.002
18	1.400	7.1	317	21.0	222	139.2	0.003
19	1.200	7.4	313	32.0	276	134.6	0.001
20	1.400	7.5	230	32.0	215	108.2	0.001

3.6 Metals determined in the leachate of the wet column whit mine waste rock

Similarly, the metals present in the waste rock (See Table 6), upon weathering are solubilized in the wet column and upon encountering other chemical elements, oxidation-reduction reactions occur where pH is an important factor, observing the fluctuation of increase and decrease of these elements seeking their chemical equilibrium, generally in more favorable conditions of neutralization; in the study of Heviánková et al. (2013) calcium carbonate was used to achieve neutrality and have better results in the treatment of mine water. The weathering that occurs in the geochemistry of the mine waste rock using the wet column where the presence of water, air, sulfides and carbonates in oxidation and hydrolysis processes, allows predicting a natural control of minerals and the generation of acid or alkaline drainage. The process that occurs in the wet column can be represented by Eq(5).

$$FeS_2 + 2\ CaCO_3 + 7/2O_2 + H_2O \rightarrow Fe\ (OH)_3 + 2SO4^{-2} + 2Ca^{+2} + 2H_2CO_3 \qquad (5)$$

Table 6: Metals in mine waste rock leachates

week	Pb (mg/l)	Zn (mg/l)	Fe (mg/l)	Mn (mg/l)	Cd (mg/l)	As (mg/l)	Hg (mg/l)	Ca (mg/l)
1	0.040	0.036	0.150	0.159	0.0006	0.0033	0.00029	156.3
2	0.050	0.048	0.009	1.547	0.0029	0.0035	0.00031	222.8
3	0.018	0.032	0.020	1.273	0.0012	0.0029	0.00034	146.7
4	0.001	0.025	0.025	0.907	0.0001	0.0033	0.00035	131.5
5	0.008	0.024	0.014	0.876	0.0015	0.0031	0.00029	99.4
6	0.030	0.014	0.017	0.197	0.0009	0.0029	0.00031	99.4
7	0.001	0.004	0.015	0.008	0.0002	0.0027	0.00033	50.5
8	0.001	0.011	0.028	0.237	0.0007	0.0033	0.00032	35.3
9	0.001	0.007	0.017	0.027	0.0002	0.0035	0.00034	44.1
10	0.010	0.058	0.043	0.323	0.0004	0.0027	0.00028	42.5
11	0.001	0.011	0.026	0.607	0.0005	0.0025	0.00027	56.1
12	0.001	0.012	0.032	0.560	0.0002	0.0021	0.00025	50.5
13	0.007	0.015	0.059	0.554	0.0007	0.0022	0.00026	53.7
14	0.005	0.013	0.064	0.457	0.0003	0.0019	0.00028	60.1
15	0.010	0.009	0.170	0.265	0.0002	0.0017	0.00031	45.7
16	0.007	0.013	0.127	0.516	0.0010	0.0015	0.00023	51.3
17	0.014	0.006	0.050	0.221	0.0002	0.0019	0.00027	60.9
18	0.009	0.039	0.119	0.177	0.0005	0.0021	0.00021	56.9
19	0.023	0.028	0.259	0.144	0.0001	0.0023	0.00019	54.5
20	0.010	0.067	0.218	0.139	0.0002	0.0016	0.00014	44.9

4. Conclusions

Using a wet column, it was possible to evaluate the drainage that occurs in the mining waste in a weathering process, allowing to determine if these drainages are of an acidic nature that may have a negative impact on receiving bodies such as soil or water sources. For the study it was obtained that by controlling the process with physicochemical and geochemical analyses the nature of the leachates is determined; in this case, the drainage was in the neutral range due to the presence mainly of carbonates (calcite and rhodrosite), sulfides and oxides, which intervened in the balance of chemical reactions in the wet test column. This information allows for better decisions in the management of this type of mining waste and does not generate a negative impact on the environment.

Acknowledgments

The authors would like to thank "Investiga UCV" of the Universidad César Vallejo for financial support for the publication of this research.

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