Use of Anaerobic Reactors for AMD Passive Treatment from a Waste Pile–Jacobina Mine

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ABSTRACT

Acid mine drainage (AMD) generation is one of the greatest challenges for mine water management and treatment. An alternative treatment for AMD is the application of passive systems that include the use of sulfate-reducing bacteria. This study aimed to evaluate the applicability of anaerobic bench-scale reactors to remove the presence of aluminum in the effluent from a waste pile of a gold exploration. Five anaerobic reactors were applied in parallel with different proportions of substrates composed by limestone, sugar cane bagasse, a leguminous species, manure and sawdust. A source of iron was also added into two of the studied reactors. The results suggest an aluminum removal higher than 99 % for all reactors. The pH of the reactors effluents was naturally kept over 6.0 during the whole study.

Keywords: AMD effluent treatment, anaerobic reactors

INTRODUCTION

Jacobina mine is a complex of underground gold mine located in the town of Jacobina in Bahia state Brazil and it belongs to YAMANA GOLD INC. Now a days this mine process 6,500 tons of ore per day in activated carbon pulp processing plant, this production started in 2005.

The occurrence of acid mine drainage (AMD) has been reported in the extraction of commodities such as gold, coal, copper, zinc and uranium. Sulphide minerals are formed under reducing conditions and therefore in the absence of oxygen. These minerals, when exposed to atmospheric oxygen due to excavation and deposition of tailings, they can become unstable and oxidize.

AMD is therefore the result of natural oxidation of sulphide minerals such as pyrite (FeS_2) and pyrrhotite ($Fe_{(1-x)}O$) when exposed to water and oxygen, and this chemical reaction action can be accelerated in the presence bacteria. AMD usually has a low pH (1.5 to 3.5) and high levels of dissolved sulphate and metals.

The passive treatment systems refer, in general, processes which do not require human intervention to regulate the activities of operation. Such systems are usually constructed from locally found materials (soils, clays and rock fragments), natural materials (crop residues such as straw, wood shavings, manure) to promote the growth of natural vegetation or to promote an environment where effluent treatment can occur through microbial activity.

Typically passive systems can be characterized by promoting water flow by gravity, by having long operation years without demanding equipment that requires electrical power supply.

The passive treatment has been applied to the detriment of several alternatives due to their low cost of deployment and maintenance processes. However, passive wastewater treatment is only possible to be applied in cases where the triad, effluent quality, flow and availability of area allows your application with greater probability of success.

The aim of this study is to present the results of the implementation of a passive system of anaerobic bench scale, applied to the treatment of acid mine water produced in the waste dump known by the name of João Belo and located at Jacobina Mining Corporation (JMC) that belongs to Yamana GOLD INC.

METHODOLOGY

Study area

The study area is comprised by the JMC mine, located in the town of Jacobina in Bahia State Brazil and belongs to YAMANA GOLD INC. The experimental apparatus is located downstream from the waste dump João Belo after the flooded area formed by the drain from the battery.

Characterization of DAM and early treatment

The characterization of the effluent from the mine waste dump was obtained from a sampling campaign conducted in August 2011, where the chemical of interest for treatment were determined. The mine effluent results were compared with the maximum concentration limits (MCL) of Brazilian water surficial water quality criteria (CONAMA 357/2005) for class 2 over the limits for effluent discharge.

Table 1 presents the results of this campaign, which also reports the results of detection, the legal concentration limit of the Brazilian regulation CONAMA 357/2005 for Class 2 water bodies and the analytical method employed. All components were dissolved and analyzed for their overall shapes.

Table 1 Characterization of acid drainage from the waste dump.

Chemical	DL(mg/L) (1)	JMC-03-tot (2)	JMC-03-dis(2)	MCL (mg/L) (3)	Chemical of interest	Analytical Method(4)
Al	0.0078	20.120	20.002	0.1	Yes	ICP-AES
As	0.0366	BDL	BDL	0.01	No	ICP-MS
Cd	0.0011	0.004	0.003	0.001	Yes	ICP-MS
Co	0.0023	0.203	0.199	0.05	Yes	ICP-AES
Cr	0.0026	0.127	0.127	0.05	Yes	ICP-AES
Cu	0.0005	0.123	0.122	0.009	Yes	ICP-AES
Fe	0.0021	1.789	1.753	0.3	Yes	ICP-AES
Mn	0.0003	1.171	1.150	0.1	Yes	ICP-AES
Ni	0.0017	0.223	0.219	0.025	Yes	ICP-AES
P	0.1043	BDL	BDL	0.02	No	Ion chrom
Pb	0.0176	BDL	BDL	0.01	No	ICP-MS
Sb	0.0133	BDL	BDL	0.005	No	ICP-MS
Se	0.0393	BDL	BDL	0.01	No	ICP-MS
SO_4	0.1200	186.640	184.366	250	No	ICP-AES

(1) DL: detection limit of the parameter;
(2) Metal Concentration in Total and Dissolved Forms
(3) Maximum Concentration Level for Water Bodies Class 2 According to CONAMA 357/2005.
(4) ICP-AES: Inductively Couple Plasma – Atomic Emission Spectroscopy
(4) Ion chrom: Ion Chromatograph

As noted, the main constituents of interest were those whose concentration is found above the legal limits for class 2 rivers, especially aluminum, whose concentration was 20 mg / L or approximately 1.0×10^{-3} mol / L.

The principle of treatment is guided by the fact that 0.3 moles of sulfide will be produced per cubic meter per day in the reactors. Each reactor contains about 150L to 200L of substrate and, consequently, each reactor should be capable of generating 0,045 moles of sulfide according to the following reaction.

$$2\,H^{+} + SO_4^{=} + 2\,\text{“}CH_2O\text{”} \longrightarrow H_2S + 2\,HCO_3^{-} \qquad (1)$$

In the reaction, "CH2O" generically represents the organic matter present in the reactors. The contaminants are removed by two geochemical mechanisms. The H_2S generated by the reaction above reacts with Fe, Zn, Cu, Cd and Pb metals generating precipitated sulfides (secondary sulfides).

$$H_2S + Zn^{2+} \longrightarrow ZnS + 2\,H^{+} \qquad (2)$$

Furthermore, HCO_3 increases the pH and form metal hydroxide precipitates, which will be important process for removing aluminum and chromium.

$$Al^{3+} + 3\,HCO_3^{-} \longrightarrow Al(OH)_3 + 3\,CO_2 \qquad (3)$$

According to the reactions as shown and the aluminum concentration found in the effluent, 2 moles of HCO_3^- are released for every mole of H_2S and 3 moles of HCO_3^- are necessary to 1 mol of aluminum be removed. Consequently, 0.045 mol of sulfide is generated in the reactors 0.030 mole of aluminum can be removed. Thus, 30L of water a day can be processed in reactors containing 150L to 200L of substrate, which corresponds to a rate of 20,5mL / min.

Experimental apparatus

The passive system deployed on the site consists of five anaerobic pilot scale with volume of 250L, which in turn receive the effluent from the mine waste dump. The effluent distribution system consists of a feed tank of 1,000L which forwards the effluents by gravity to five tanks/ of 50L, which in turn feed the reactors. The feed rate of each reactor is 30L / d. Figure 1 below shows a schematic of the system implementation.

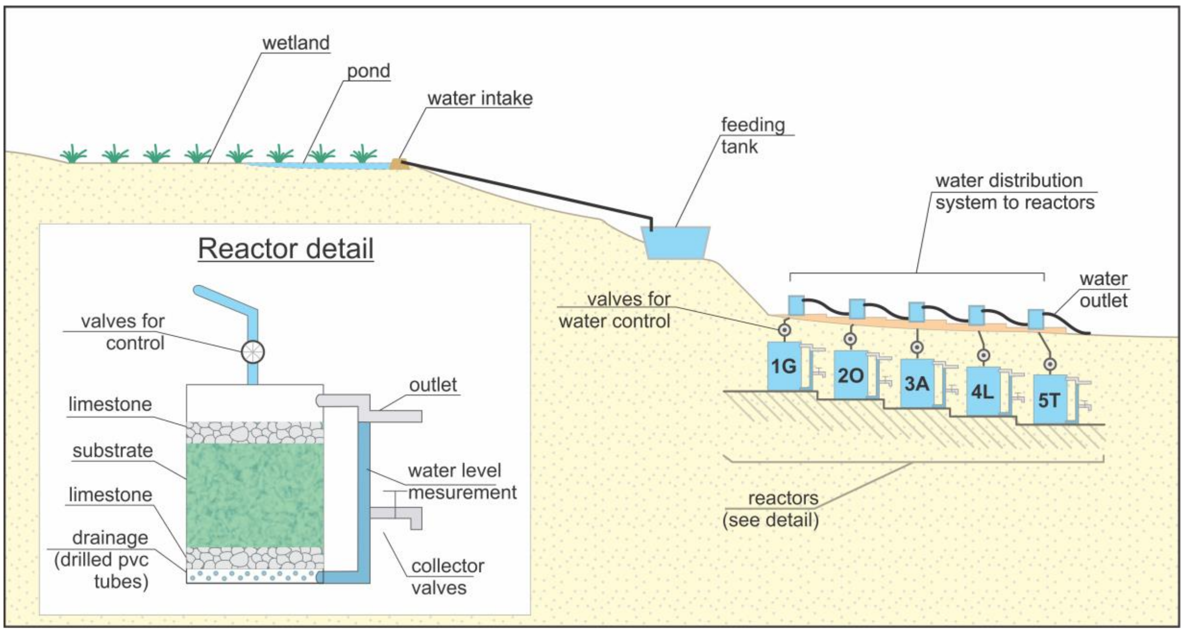


Figure 1 Bench scale passive treatment system developed in the Jacobina mine, belonging to Yamana Gold

The five reactors were sized to receive a limestone layer disposed on top of the substrate and a layer on the bottom of the reactor. The composition of the substrate comprises carbon sources, nitrogen, and an inoculum (manure), and a source of iron was added in two reactors. Table 2 below shows the composition of the substrates used in each reactor. The percentage of substrate used is relative to the working volume of the reactors (150L).

Table 2 Materials used for the substrate filled in each reactor.

Substrate	Reactors				
	1 G	2 O	3 A	4 L	5 T
Wood dust	40%	20%	30%	35%	40%
Limestone	30%	30%	25%	30%	30%
Sugarcane bagasse	-	10%	10%	15%	20%
Legume vegetation	20%	15%	15%	10%	-
Steel dust	-	10%	10%	-	-
Manure	10%	10%	10%	10%	10%

Monitoring and start-up system

After the implementation of the reactors on the site, the substrate was inserted into each reactor composition as indicated in Table 2. The start-up of the system was performed by maintaining the water level of the reactor above the substrate for a period of one week, so that the community of sulfate-reducing bacteria could be established in the system. For monitoring system, samples of effluent from the waste dump and effluents from the treatment of the five reactors were collected monthly between the months of October 2011 to March 2012. The monitored parameters were: temperature, pH, electrical conductivity and alkalinity. For monitoring the efficiency of the system, the concentrations of sulfate and metals aluminum, manganese and iron, in its dissolved form, were analyzed. The parameters of interest were analyzed according to Standard Methods for the Examination of Water and Wastewater. Metal concentrations in the influent and effluent of the system were analyzed through atomic emission spectrometry (ICP-AES) techniques.

RESULTS AND DISCUSSION

Table 3 shows the results of the concentrations of dissolved aluminum dissolved iron dissolved manganese sulfate, and pH from monitoring the influent and effluent produced by the five reactors.

Table 3 Results in mg/L of passive monitoring system for treatment of AMD.

Parameter	Average concentration (Parameter reduction - %)					
	In take	1G	2O	3A	4L	5T
Al	20,7	0,02 (99,9)	0,02 (99,9)	0,02 (99,9)	0,02 (99,9)	0,03 (99,8)
Fe	1,44	0,01 (99,6)	0,05 (96,4)	1,41 (2.17)	0,32 (77,3)	0,01 (99,3)
Mn	1,95	2,21 (25.1)	2,23	3,15	2,48	1,26 (35,5)
SO_4	209.21	75,7(63.8)	32,4 (84.5)	27,9 (86.6)	23.07 (88.9)	134,5 (35.7)
pH	3,03	7,47	7,14	6,89	6,98	7,39

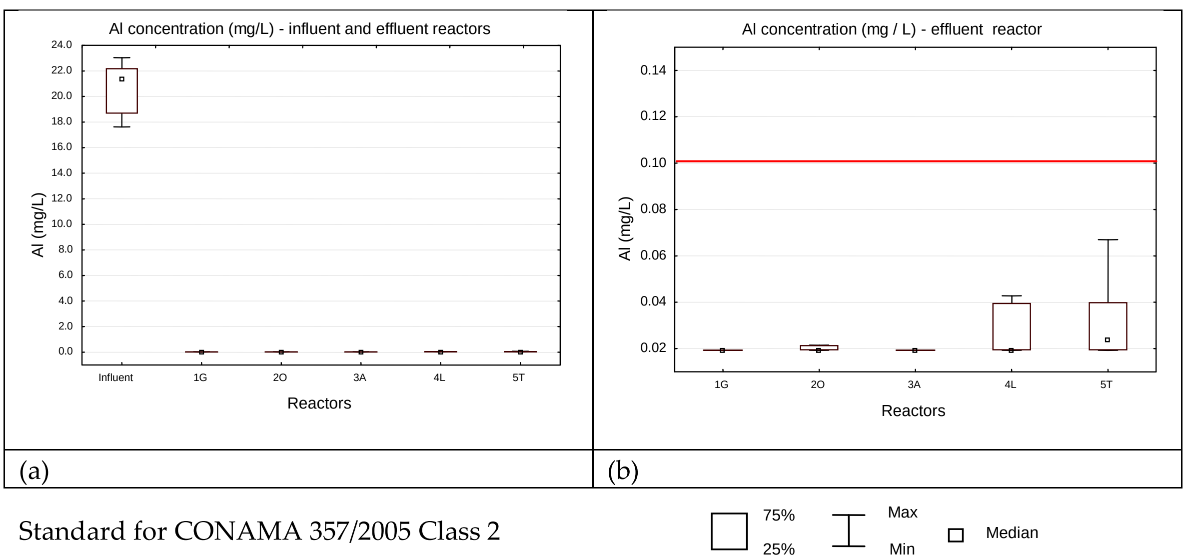
As noted in Table 3, the average concentration of aluminum in the tributary system is 20,7mg / L and the effluent of the reactors yielded concentrations below 0.04 mg / L. The average efficiency for all reactors was greater than 99.8% removal of aluminum.

In the characterization of AMD produced on site, the main element of interest was the treatment of aluminum metal. The iron was introduced into the substrate only to promote coprecipitation of metal, so the high concentration observed in the effluent of reactor 3A is a consequence of the removal of iron present in the substrate. As noted, 10% by volume of the reactors of the substrate 2O and 3A is constituted of iron filings. Although the same amount of iron has been added in the substrate from both reactors, the reactor effluent showed 2O average concentration of 0.05 mg / L, and the effluent from the reactor had an average concentration 3A iron 1,41mg / L. Regarding other reactors, lower average concentrations to 0.4 mg / L was observed.

As noted, the increased manganese concentrations in the effluents of the reactors. The average concentration of manganese was 1,95mg / L and the influent was noted that the effluent from the reactors had concentrations above the value observed for influent. Due to the fact that manganese may be present in the crystal structure of carbonate minerals (e.g., rhodochrosite - $MnCO_3$), the increase in the average concentration in the effluent of the reactors can be attributed to solubilization of manganese present in the limestone.

With respect to pH, it was noted that the composition of the substrate was able to raise the pH of the effluents from all reactors. The average concentration of the effluent was pH 3.03 (in take) and the average concentrations of the effluent of the reactors were maintained pH between 6 and 8.

Efficiency in removing sulfate above 60% for all reactors except reactor 5T, whose average efficiency was 35.7% although the goal of treatment has not been the removal of sulfate, this was observed.

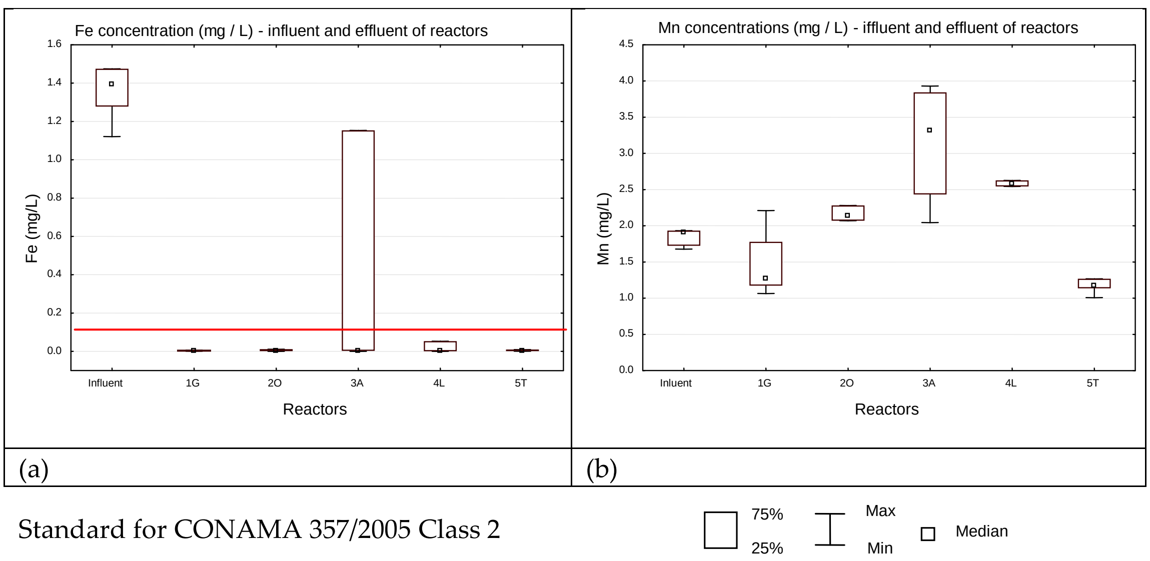


Graph 1 Concentrations of aluminum in the influent and effluent of the reactors.

The graphs (Figure 1) show the different aluminum concentrations in the influent and effluent of the reactors. Plot (a) shows the inflow concentrations compared to the effluent quality of the system. The graph (b) shows the effluent concentrations of the reactors and the limit for aluminum according to CONAMA No. 357 of 2005 for class 2 [4] water bodies.

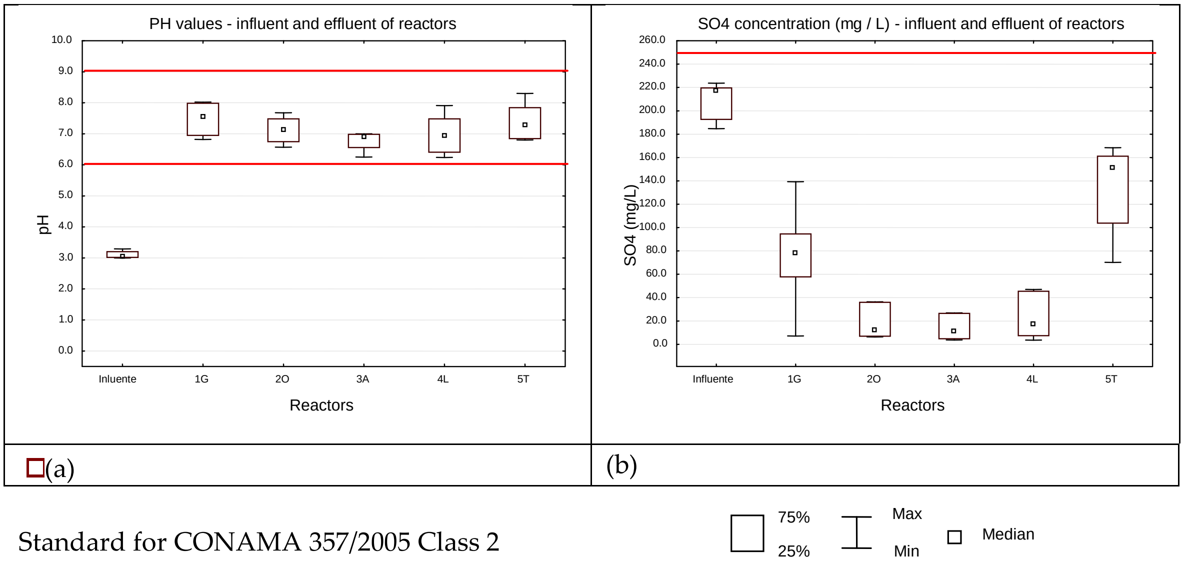
It is observed that the average aluminum concentration in the influent of the reactor is between 20 and 22 mg / l. For effluent concentrations, we note that the maximum, minimum and median values have little variability for 1G, 3A and 2O reactors, while for the other reactors, 4L and 5T, concentrations were more variable, with maximum values exceed 0.04 mg / l. In fact, the effluent concentrations of aluminum were often below the detection limit of the analytical method in order to justify the stability of the observed values. It is seen that the concentrations of the effluent from reactor consistently met the threshold practiced 0.1mg / l.

Chart 2 below shows the concentrations of iron and manganese influent and effluent of the reactors.



Graph 2 Concentrations of iron (a) and manganese (b) in the influent and effluent of the reactors.

The graphs show the concentrations of iron (a) and manganese (b) in the influent and effluent of the reactors. The iron concentration in the influent have a median value of 1.4mg / l and the effluent have median values below 0.1 mg / l. As previously mentioned, the source of iron present in the substrate may have contributed to the increase in concentration in the reactor effluent 3A. With respect to the concentrations of manganese, there is greater variability in the distribution of concentrations from reactor 3A, whose median was approximately 3,4mg / L.



Graph 3 Values of pH (a) sulfate and (b) in the influent and effluent of the reactors.

As noted, the pH values consistently complied with the environmental laws, whose values should be between 6.0 and 9.0. Given that the median pH of the influent was approximately 3.0, the limestone used as the substrate alkalinity produced by anaerobic activity in the system was able to elevate and maintain the pH of the reactors to values above 6.0.

According to the graph (b) of the figure, we note that the sulfate median concentrations in the reactors 2O, 3A and 4T, were below 20,0mg / L. In comparison with the inflow concentrations, the removal of sulfate in the reactor was 63.4%, 84.5%, 86.6%, 88.9% and 35.7% for the 1G 2O, 3A, 4L reactor and 5T respectively. It is also noticed that the effluents did not exceed the maximum concentrations of 250 mg / L of sulfate, as pointed out by environmental legislation.

Regarding other metals characterized in acid drainage from the waste dump of João Belo, it was noted that their concentrations were below the detection limit of the analytical method used in all analyzes.

CONCLUSIONS

In accordance with the observed results, it can be concluded that all reactors are capable of complying with the procedure outlined for treatment of acid drainage from the waste dump John Belo, mine JMC main objective. It was observed that all reactors were able to reduce aluminum concentrations below the limit of 0.1 mg / l recommended by law. The mechanism for aluminum reduction is due to the precipitation of this metal as hydroxides, as it was mentioned before.

The production of alkalinity caused by anaerobic activity, as well as limestone applied to the substrate, greatly increased the pH of all reactors applied in passive treatment so that the effluent met the minimum and maximum limit recommended by law.

With respect to iron and manganese in the effluent of the reactors analyzed, it was noted that their concentrations exceeded the limits prescribed by law due possibly to the fact that these metals are present in the chemical composition of the substrate applied.

Considering the low cost of the ingredients and this stage of this effluent treatment study it was not necessary to develop cost estimation among the different reactors for a full scale implementation. Once this project moves to the next phase, a cost evaluation for the implementation of the different reactors will be developed. So the mine company would have the best cost / return ratio for this effluent treatment system.

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