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Analysis and Evaluation onthe Treatment System Optimization for Mine Acid Drainage with Natural Dolomite at Sociedadminera El Brocalcompany

Lawrence Quipuzco[1]*, Erik Olivera[1], Daniel F. Lovera[2], Walter Pardavé[3]
1 Universidad NacionalAgraria La Molina Perú..
2 Department of Metallurgical Engineering, Universidad Nacional Mayor de San Marcos, Lima, Perú.
3 Environmental Group of Applied Research, Universidad de Santander, UDES, Bucaramanga, Colombia
Corresponding Author: Lawrence Quipuzco

ABSTRACT:*The research evaluated the technical and economic viability of taking advantage of dolomite used as a remediating agent for acid drainage in a mining company that currently uses lime. The dolomite and the acid drainage were characterized, the dolomite was conditioned to different granulometry and the processes and costs of the conventional treatment were described. Lixiviation tests were carried out evaluating dolomite effectiveness and also its combination with lime to obtain technically feasible treatment alternatives. Costs of the alternatives were projected to calculate the cost-effectiveness coefficients and their comparing with the conventional system to determine the economic viability. Three alternatives that include dolomite exploiting and the reduction of heavy metals concentration according to Peruvian legislation was determined. The alternatives correspond to the dosages of 0.4 g of natural dolomite with 0.03 g of lime; 0.3 g of calcined dolomite with 0.04 g of lime; 0.4 g of calcined dolomite with 0.03 g of lime. Its cost-effectiveness coefficients were 0.58, 0.64 and 0.62 Soles/m3, while in the conventional system it was 0.68 Soles/m3, reducing costs by 15%, 6% and 9% demonstrating techno-economic viability of dolomite use. The costs of sludge management, personnel, equipment, energy and supplies were also considered.*

KEYWORDS: *Dolomite, mine acid drainage, cost-effectiveness coefficient, heavy metal removal, alternatives, viability*

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I INTRODUCTION

The first achievements in studies concerning dolomite used as a heavy metals removal and acid decreasing agent were made in North Ireland, Africa, Turkey and Peru between 2004-2009. Walker (2009) proved a significant removal of copper on industrial textile effluent with granulometry and thermally treated dolomite, besides Pehvilan (2009) studied the adsorption phenomena of copper and lead ions of analytic solutions with milled dolomite. Likewise, Flores (2009) researched on copper adsorption in analytic solutions of copper sulphate and effluents coming from the mineral flotation pilot plant with granulometry and thermally treated dolomite.

In addition to the study of dolomite as an adsorption and heavy metals removal agent, the contribution of the current research was to evaluate the technical and economic viability of using this resource considering the real conditions of a mining company, employing cost-effectiveness coefficient as an important tool in decision making within companies. For this purpose, materials, labor, supplies, energy, equipment investment and dolomite extraction and processing costs were also calculated as well as avoided expenses related with pool cleaning and sludge transportation. A new alternative for the company SociedadMinera El Brocal was determined by the research and it was provided an application for the unused resource.

II MATERIAS AND METHODOLOGY

2.1 Materials

For research development, the fundamental materials and equipment used in the laboratory scale lixiviation tests were Magnatrade branded polyacrylamide-based flocculent, calcium hydroxide, calcined and non-calcined dolomite with different granulometry and one-liter Imhoff cones. Moreover for the laboratory scale treatment system, venoclysis equipment and three inches thickness polystyrene foam was used. For the natural dolomite preconditioning was used a jaw crusher, a cone crusher, a pulverizer, milling equipment, a LabtechHebro branded sieve with "Standard Screen 1910" series International Tyler screens and a muffle furnace.

2.2 Methodology

The investigation was based on studying and evaluating natural dolomite as a feasible supply into acid water treatment. To do so, the outcrop main area was identified to made sampling and characterization. After that, the natural dolomite was prepared into different grain sizes and calcination states. The description of the conventional treatment at Marcapunta Oeste area facilities had as purpose to define initial parameters of the lixiviation tests such as stir time and velocity, residence time and complementary supplies. Similarly, data concerning resources, personnel and needed utilities for performing treatment process were taken. Besides, the effluents characterization from the area was made. The project continued with laboratory scale comparative experiments by calcined and non-calcined natural dolomite, industrial lime and a dolomite and lime mixture to determine optimum final parameters in treatment such as optimum dose, optimum granulometry and optimum dolomite-lime ratio.

Finally, cost-effectiveness analysis of implemented process against alternatives detected during research was performed. The final effluents had to approve the current environment regulation

Statistical Analysis

The preliminary tests results were analyzed statistically by the comparative Turkey analysis. Prior to this, it was necessary to implement error normality test, variance homogeneity and variance analysis as a basic requirement of experimental design using a significance level of $\alpha=0.05$. To compare the results of the final tests numeric ranges were used to accept or reject the alternatives

III RESULTS

3.1 Dolomitecharacterization

To characterize dolomite located in Lachipana hill, it was performed a mineralogical analysis by X-Ray diffraction and a chemical analysis by atomic absorption. Obtaining the following results.

Mineralogical analysis by X-Ray diffraction

The detected mineral phases in the sample was dolomite and quartz. It was obtained a detailed diffractogram (Figure 1). From this was informed the quantification of the presented phases, using Rietveld refinement process showing the quantitative results of dolomite 99% ($CaMg(CO_3)_2$) and quartz 1% ($(SiO)_2$). According to Ruiz (2015), the quartz presence in the treatment does not represent a threat in the treated effluent water quality; the quartz molecule has a high hardness and chemical resistance.

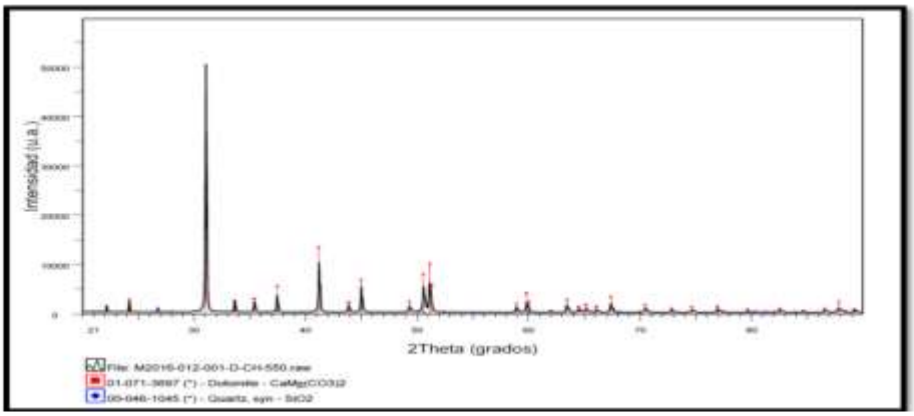

Figure1. The diffractogram shows the existence of two mineral phases. The red colored diffraction

peakscorresponding the dolomite phase whit calcium carbonates and magnesium ($CaMg(CO_3)_2$), while blue colored
diffraction peaks corresponding to quartz phase (SiO_2).

3.2 Characterization of the mine acid drainage

For characterization of the mine acid drainage without treatment, it was measured the concentration of total metals and pH level the results are shown in Table 1. From these results it is highlighted that mine acid drainage without treatment presents copper and iron concentrations which average values were 8.63 mg/L and 10.02 mg/L respectively, these values exceed to 0.4 mg/L and 1.6 mg/L which are the annual average limits for effluents.. Furthermore, it was noticed a considerable zinc concentration whit an average of 0.48 mg/L. However, it does not exceed the environment limit for mine effluents of 1.2 mg/L. On other hand the average pH of the acid drainage without treatment was 3.83 which value is out of the annual average limit of 6-9 allowed for mine effluents. Reasons enough to consider copper, iron and zinc parameters as critical variables.

Sample	**Total metals mg/L**						**pH**
	Cd	**Mn**	**Pb**	**Zn**	**Cu**	**Fe**	
A	0.01	0.14	0.17	0.35	9.41	10.94	3.80
B	0.01	0.12	0.20	0.31	9.57	10.92	3.79
C	0.01	0.33	0.11	0.61	9.07	10.60	3.99
D	0.01	0.33	0.05	0.61	9.01	10.85	4.01
E	0.01	0.310	0.07	0.490	7.330	8.440	3.7
F	0.01	0.350	0.08	0.480	7.380	8.350	3.68
Average	0.01	0.26	0.11	0.48	8.63	10.02	3.83

Table 1. Results of the concentration measure for total metals in mine effluents without treatment

3.2 Lixiviation tests

Preliminary tests

Natural calcined and non-calcined dolomite was used for the preliminary tests with a corresponding granulometry of 59, 113, 195, 304 and 440 micrometers, and 0.5, 1, 1.5, 2, 2.5 grams doses. These tests provoked the effluent neutralization; yield variable of each test was associated to pH percentage increase.


Comparaciones para rendimiento neutralizacion

Comparaciones por parejas de Tukey: Respuesta = rendimiento neutralizacion, Término = granulometria

Agrupar información utilizando el método de Tukey y una confianza de 95%

granulometria	N	Media	Agrupación		
113 micras	5	0.640	A		
304 micras	5	0.620	A	B	
440 micras	5	0.610	A	B	
195 micras	5	0.582		B	
59 micras	5	0.516			C

Las medias que no comparten una letra son significativamente diferentes.

Figure 2. It is observed in the figure that natural dolomite with a granulometry of 113, 304 and 440 microns are classified in group A with the highest neutralization yields of 64%, 62% and 61% respectively, and they are statistically similar.

Comparaciones para rendimiento neutralizacion

Comparaciones por parejas de Tukey: Respuesta = rendimiento neutralizacion, Término = granulometria

Agrupar información utilizando el método de Tukey y una confianza de 95%

granulometria	N	Media	Agrupación		
440 micras	5	0.682	A		
113 micras	5	0.678	A		
304 micras	5	0.616		B	
195 micras	5	0.548			C
59 micras	5	0.522			C

Las medias que no comparten una letra son significativamente diferentes.

Figure 3. It is observed in the figure that calcined dolomite with a granulometry of 440 and 113 microns are classified in group A have the highest neutralization yields with 69% and 68% percent respectively, and are statistically similar.

For calcined and non-calcined dolomite, it was determined that 113 micrometers granulometry was the most efficient one. Data were obtained by the Turkey comparison test and showed in Figure 2 and 3. The minimum needed doses of the effluent preconditioning to obtain pH values over 5 were 0.2, 0.3 and 0.4 of calcined and non-calcined dolomite. These results are presented in Table 2 and 3.

Dolomite 113 micrometers non-calcined		
dose (grams)	**pH initial**	**pH final**
0.1	3.4	4.56
0.2	**3.4**	**5.04**
0.3	**3.4**	**5.18**
0.4	**3.4**	**5.29**
0.5	3.4	5.44
1	3.4	5.54
1.5	3.4	5.77
2	3.4	5.83
2.5	3.4	5.93

Table 2. pH values before and after the pre-treatment using non-calcined dolomite.

Dolomite 113 micrometers calcined		
doses (grams)	**pH initial**	**pH final**
0.1	3.7	4.9
0.2	**3.7**	**5.33**
0.3	**3.7**	**5.40**
0.4	**3.7**	**5.52**
0.5	3.7	5.6
1	3.7	5.88
1.5	3.7	6.1
2	3.7	6.34
2.5	3.7	6.55

Table 3. pH values before and after the pre-treatment using calcined dolomite.

Prototype tests

The prototype tests were performed using the optimum calcined and non-calcined dolomite doses for the pretreatment, these corresponding to 0.2, 0.3, and 0.4 grams per liter of effluent. Every test used lime complementary doses of 0.03, 0.04, 0.05 and 0.06 with the purpose of completing dolomite neutralization. The results of the prototype tests was collected in the Table 4 and 5. From these results, the best possible scenario using non-calcined dolomite –including a 58% lime save– was the mixture of 0.4 grams of dolomite and 0.03 grams of lime, which complying with the established limits for copper, iron and zinc. Likewise, for calcined dolomite the best scenarios were those lime save were 44% and 58% and had mixtures of 0.3 dolomite grams and 0.04 lime grams and 0.4 dolomite grams and 0.03 lime grams respectively.

Non-calcined dolomite	Initial concentration (mg/L)			Final concentration (mg/L)			% Removal		
	Zn	Cu	Fe	Zn	Cu	Fe	Zn	Cu	Fe
0.2 Dolom.+ 0.03 Lime	0.61	9.04	10.73	0.19	**0.49**	0.29	69%	95%	97%
0.2 Dolom.+ 0.04 Lime	0.61	9.04	10.73	0.16	**0.44**	0.25	74%	95%	98%
0.2 Dolom.+ 0.05 Lime	0.61	9.04	10.73	0.17	0.32	0.23	72%	96%	98%
0.2 Dolom.+ 0.06 Lime	0.61	9.04	10.73	0.14	0.28	0.25	77%	97%	98%
0.3 Dolom.+ 0.03 Lime	0.61	9.04	10.73	0.17	**0.42**	0.17	72%	95%	98%
0.3 Dolom.+ 0.04 Lime	0.61	9.04	10.73	0.14	**0.40**	0.30	77%	96%	97%
0.3 Dolom.+ 0.05 Lime	0.61	9.04	10.73	0.12	0.29	0.27	80%	97%	97%
0.3 Dolom.+ 0.06 Lime	0.61	9.04	10.73	0.13	0.20	0.25	79%	98%	98%
0.4 Dolom.+ 0.03 Lime	**0.61**	**9.04**	**10.73**	**0.12**	**0.35**	**0.24**	**80%**	**96%**	**98%**
0.4 Dolom.+ 0.04 Lime	0.61	9.04	10.73	0.09	0.33	0.17	85%	96%	98%
0.4 Dolom.+ 0.05 Lime	0.61	9.04	10.73	0.10	0.40	0.24	84%	96%	98%
0.4 Dolom.+ 0.06 Lime	0.61	9.04	10.73	0.08	0.36	0.18	87%	96%	98%

Table 4. Results of the prototype tests with non-calcined dolomite and lime

Calcined dolomite	Initial concentration (mg/L)			Final concentration (mg/L)			% Removal		
	Zn	Cu	Fe	Zn	Cu	Fe	Zn	Cu	Fe
0.2 Dolom. + 0.03 Lime	0.49	7.36	8.40	0.09	**0.40**	0.35	81%	95%	96%
0.2 Dolom.+ 0.04 Lime	0.49	7.36	8.40	0.12	**0.40**	0.30	75%	95%	96%
0.2 Dolom.+ 0.05 Lime	0.49	7.36	8.40	0.09	**0.43**	0.52	81%	94%	94%
0.2 Dolom.+ 0.06 Lime	0.49	7.36	8.40	0.10	**0.46**	0.42	79%	94%	95%
0.3 Dolom.+ 0.03 Lime	0.49	7.36	8.40	0.12	**0.41**	0.48	75%	94%	94%
0.3 Dolom.+ 0.04 Lime	0.49	7.36	8.40	0.07	0.24	0.40	**86%**	**97%**	**95%**
0.3 Dolom.+ 0.05 Lime	0.49	7.36	8.40	0.08	0.37	0.28	84%	95%	97%
0.3 Dolom.+ 0.06 Lime	0.49	7.36	8.40	0.08	0.36	0.34	84%	95%	96%
0.4 Dolom.+ 0.03 Lime	0.49	7.36	8.40	0.11	0.30	0.59	**77%**	**96%**	**93%**
0.4 Dolom.+ 0.04 Lime	0.49	7.36	8.40	0.10	0.35	0.52	79%	95%	94%
0.4 Dolom.+ 0.05 Lime	0.49	7.36	8.40	0.09	0.36	0.34	81%	95%	96%
0.4 Dolom.+ 0.06 Lime	0.49	7.36	8.40	0.08	0.34	0.30	84%	95%	96%

Table 5. Results of the prototype tests with calcined dolomite and lime

The alternatives to take advantage of dolomite on the treatment of mine acid drainage are summarized as three, the first one (0.4 g non-calcined dolomite and 0.03 g lime), the second one (0.3 g calcined dolomite and 0.04 g lime) and the third one (0.4 g calcined dolomite and 0.03 g lime).

The removal yield of the first one was 96% for copper and 98% for iron, the second one was 97% for copper and 98% for iron and the third one was 96% for copper and 93% for iron.

Sludges generation

The amount of sludge generated in the prototype tests was determined by the methodology of determination of sedimentable solids in Inhoff cones (DINAMA Laboratory, 1996). In the lixiviation tests, it was determined that lime generates an average of 9.45 ml of sludge per liter of treated acid drainage. While using dolomite without calcination with lime generates an average of 4.25 ml of sludge per liter of treated acid drainage. On the other hand, the use of calcined dolomite generates an average of 3.96 ml of sludge per liter of treated acid drainage (Table 6 and 7). Then there is evidence that the solids generated in the conventional treatment with lime as a primary supply generates greater volumes of sludge which represents a problem for the treatment plant as the sediment deposit will be filled in less time. This implies an increase in the frequency of cleaning generating more costs for concepts of machinery rental, labor, transport and final disposal of the sludge.

Non-calcined dolomite	Sludge volume (ml)	Calcined dolomite	Sludge volume (ml)
0.2 D.SC + 0.03 Lime	5.4	0.2 D.SC + 0.03 Lime	3.5
0.2 D.SC + 0.04 Lime	5.6	0.2 D.SC + 0.04 Lime	3.9
0.2 D.SC + 0.05 Lime	5.9	0.2 D.SC + 0.05 Lime	4
0.2 D.SC + 0.06 Lime	6	0.2 D.SC + 0.06 Lime	4.25
0.3 D.SC + 0.03 Lime	3.5	0.3 D.SC + 0.03 Lime	3.6
0.3 D.SC + 0.04 Lime	3	**0.3 D.SC + 0.04 Lime**	**4.1**
0.3 D.SC + 0.05 Lime	3.9	0.3 D.SC + 0.05 Lime	4.25
0.3 D.SC + 0.06 Lime	4	0.3 D.SC + 0.06 Lime	4.3
0.4 D.SC + 0.03 Lime	**3**	**0.4 D.SC + 0.03 Lime**	**3.7**

0.4 D.SC + 0.04 Lime	3.3	0.4 D.SC + 0.04 Lime	4.1
0.4 D.SC + 0.05 Lime	3.6	0.4 D.SC + 0.05 Lime	3.9
0.4 D.SC + 0.06 Lime	3.8	0.4 D.SC + 0.06 Lime	3.9
Average	4.25	Average	3.958

Table 6. Volumes of sludge generation in pilot tests

Lime (grams)	Sludge volume (ml)
0.03	8.8
0.04	9.3
0.05	9.7
0.06	10
Average	9.45

Table 7. Volumes of sludge generation in pilot tests against lime doses

Cost-effectiveness analysis

It is observed that the cost - effectiveness coefficient for the conventional treatment system is S/.0.68 per cubic meter, while alternative 1, 2 and 3 the cost-effectiveness coefficients are S/.0.58, S/.0.64 and S/.0.62 per cubic meter respectively, the details of the data are summarized in Table 8.

IV DISCUSSION

In the results of heavy metals removal, it was observed that both calcined and non-calcined dolomite had similar yields, this does not agree with the theory of better acting of calcined dolomite (Flores, 2009). This happened because in the lixiviation tests, the calcined dolomite did not dissolve completely and small conglomerates formed at the bottom of the container were detected. These insoluble conglomerates were generated because of the high calcination temperatures necessary to obtain calcined dolomite. The insoluble conglomerate resembles the so-called Clinker, which is a granular material resulting from the calcination of raw materials in the cement manufacturing process. This Clinker or conglomerate must necessarily go through an additional grinding process to re-establish the initial granulometry of the incoming material to calcination.

Conventional system		
Effectiveness	2838240.00	m^3/year
Cost	S/.1,932,348.02	Soles/year
CoefficientCost - Effectiveness	S/.0.68	Soles/m^3
Alternative 1		
Effectiveness	2838240.00	m^3/year
Cost	S/.1,643,558.51	Soles/year
CoefficientCost - Effectiveness	S/.0.58	Soles/m^3
Alternative 2		
Effectiveness	2838240.00	m^3/year
Cost	S/.1,818,143.53	Soles/year
CoefficientCost- Effectiveness	S/.0.64	Soles/m^3
Alternative 3		
Effectiveness	2838240.00	m^3/year
Cost	S/.1,760,469.84	Soles/year
CoefficientCost - Effectiveness	S/.0.62	Soles/m^3

Table 8. Summary of the total costs, effectiveness and cost-effectiveness coefficients for the main alternatives

The cost-effectiveness values of the alternatives proposed in the study are lower than the conventional treatment system. These values were caused by the savings from the purchase of lime and the lower amount of transport and maintenance of sludge. For example, in the cost structure it was determined that the annual cost in lime from the conventional system is S/.366'832.8 while the alternative method one (1) which uses natural dolomite as a complementary agent the annual cost in lime is S/.153'111.7, the alternative method two (2) which uses calcined dolomite as a complementary agent, the annual lime cost is S/.204'148.9 and the alternative method three (3) which also uses calcined dolomite as a complementary agent. The annual cost of lime is S/.158'629.2. As another evidence recognized in the cost structure is that the annual cost of transportation and maintenance of sludge from the conventional system is S/.302'630.4, while the annual cost of transportation and maintenance of alternatives 1, 2 and 3 are of S/.98'035.28, S/.132'134.4 and S/.119'347.2 respectively.

According to the lixiviation tests, the conventional treatment system in the Marcapunta Oeste area generates an average of 9.45 ml of sludge per liter of treated effluent, while the alternatives proposed using dolomite generate 3.96 ml of sludge on average per liter of treated effluent. Which represents a great advantage in terms of the extraction, transport and final disposal of sludge. More detailed studies are needed on the potential benefits of generating more stable and compact sludge for the environment.

V CONCLUSIONS

The natural dolomite extracted from the mining central proximity is high purity according to the results of the X-Ray mineralogy test, close to 99% for calcium carbonates and 1% for silica.The raw acid effluents coming from the Marcapunta Oeste pithead have average concentrations of copper and iron of 8.63 mg/L and 10.02 mg/L respectively and an average pH value of 3.83. Those values exceed the established limits.

The three alternatives highlighted in the prototype tests that include the use of dolomite on the treatment system proved to be more profitable than the conventional system where there is exclusive use of lime. This is demonstrated by the cost-effectiveness coefficient for the conventional system with a value of S/.0.68 per cubic meter treated, while alternative 1, 2 and 3 have coefficients of S/.0.58, S/.0.64 and S/.0.62 per cubic meter treated. This demonstrates the viability regarding the use of the dolomite, even though they involve additional expenses in the purchase of equipment, personnel and materials for the extraction and elaboration of dolomite calcined and non-calcined.

The optimum granulometry that acts with greater neutralization efficiency and that compromises a lower energy consumption for its obtaining in the grinding process is 113 micrometers for the dolomite without calcination with 64% efficiency and 113 micrometers for the calcined dolomite with 68% efficiency.

The highlighted options for the tests of optimal doses of pre-treatment of calcined and non-calcined dolomite and second, addition of supplementary dose of lime eliminated copper and iron to levels allowed by the current environmental legislation. The use of calcined dolomite does not present higher yield than dolomite without it in the experimental tests as its mentioned (Flores 2009), this is because the formation of Clinker or insoluble solids in the calcination process which reduced effectiveness in the experimental tests.

The conventional treatment system at the Marcapunta Oeste area generates 9.45 ml of sludge on average per liter of treated effluent, while the alternatives systems that use dolomite generate 3.96 ml of sludge on average per liter of treated effluent and represents a great advantage as to extraction, transport and final sludge disposition. More detailed studies are needed regarding to partial benefits on the environment of more stable and compact sludge.

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