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Kinetics of Neutralization of Polymetallic Mining Discharges from the Perkoa Zinc Deposit in Central-Western Burkina Faso

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Abstract: Oxidized and acidic mining discharges (pH between 4 and 5) from the Perkoa zinc mine in Burkina Faso consisting of waste rock, crusher rejects and mining tailings were sampled and used for neutralization tests with calcareous dolomite (for six months). The mining discharges and the calcareous dolomite were previously characterized. Columns of 60 cm length and 15 cm diameter were used for the tests. Then, 2.62 kg of calcareous dolomite was deposited on the mining discharges in each column. Two liters of deionized water are added every 15 days to each column. Samples were taken at the outlet of the columns at time intervals and then analyzed to assess the evolution of pH, electrical conductivity and contents of PHEs (Potentially Harmful Elements) over time. Following the neutralization tests on solid mining discharges, neutralization tests were also carried out on acid leachates resulting from the oxidation of these same solid mining discharges with calcareous dolomite. The results show that calcareous dolomite is very effective for the neutralization of SR (Sterile Discharges) and the precipitation of PHEs contained therein. It is also effective in buffering acidic effluents from these sterile discharges. As for other mining discharges (crusher rejects and mining residues), although calcareous dolomite is not effective in neutralizing these oxidized and acidic solid discharges, it is however effective in precipitating PHEs such as arsenic and lead. Calcareous dolomite is also effective in buffering acid leachates from these oxidized and acidic mining discharges (crusher rejects and mining tailings).

Key words: Mining discharges, zinc mine, AMD (Acid Mine Drainage), dolomite, neutralization, Perkoa, Burkina Faso.

1. Introduction

The exploitation of mineral resources is a source of income for states and also helps to combat unemployment and poverty. Burkina Faso, whose economy was formerly based on agriculture and livestock, has seen very notable development in its mining sector over the last two decades. Gold is the main substance mined and since 2005 it has become the country's leading export product ahead of cotton. In addition to manganese, which was mined in the north of the country, zinc was the third mineral substance mined. The Perkoa zinc mine in the central-western part of the country was operated from 2013 to 2022. This operation generated huge volumes of mining discharges consisting of waste rock, crusher rejects and mining residues.

These mining discharges are stored on the surface in the form of piles called waste rock piles or in tailings ponds for treatment residues. Among these discharges, those from the concentrator, which are generally composed of finely crushed rocks devoid of substances of economic interest, remain the most problematic [1].

These mining residues can undergo a significant drop in pH following the oxidation of the sulphide minerals present, which results in the generation of acidic effluents known as AMD (Acid Mine Drainage).

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For this reason, the exposure of these different discharges from the Perkoa zinc mine to climatic agents can be the cause of the generation of AMD and therefore be harmful to the environment and health.

Indeed, when these mining discharges generated by mining activity contain sulphide minerals, their exposure to oxygen, water or certain microorganisms leads to their oxidation which can produce an acid effluent (AMD) likely to solubilize the metals which have negative impacts on the environment and human health [2-4].

According to Kalin et al. [5], and by general consensus, AMD is the most critical environmental problem associated with mining. AMD is characterized by its “brick red” or yellowish coloring, the presence of a mineral acid such as sulfuric acid (H_2SO_4), heavy metals such as copper, iron, lead, zinc. The reddish coloration is typical given the high concentrations of ferric iron (Fe^{3+}) in solution and it also carries significant amounts of aluminum, magnesium, calcium and sulfates [6]. These acidic effluents represent sources of environmental pollution and particularly harmful effects on surface water (lakes, rivers, streams), aquatic life (fish in particular) and human health.

Because the mineralogy and factors affecting AMD formation vary greatly from site to site, predicting AMD potential can be extremely difficult and expensive [7]. Once the AMD is generated, several treatment methods exist including chemical treatment using calcareous materials [4, 8, 9]. The goal of neutralization is to return the acidic pH to a neutral pH using alkaline minerals such as carbonates, thereby inhibiting the solubilization of metals. Among the main carbonates, limestones and dolomites are the most used given their high neutralization potential.

The objective of this study is to evaluate the neutralization capacity of the calcareous dolomite of Tiara (West of Burkina Faso) on the polymetallic mining discharges from the Perkoa zinc mine, in the Center-West of Burkina Faso.

2. Materials and Methodology

2.1 Study Area

The Perkoa zinc mine is located in the center-west of Burkina Faso, approximately 135 km from the capital city of Ouagadougou (Fig. 1). Located at latitude 12°19′ north and longitude 2°20′ west, the climate is of the northern Sudanese type with two seasons: a long dry season from October to May with temperatures between 15 and 41 ℃, and a rainy season from June to September with minimums and maximums varying between 22 and 35.3 ℃.

2.2 Methodology

The sampling concerned the different types of discharges from the Perkoa zinc mine, namely: “oxidized” waste rock (RS), crusher discharge (RB), mining residues including the very first tailings pond represented by cell 1 (Rcel.1) and the third and last tailings pond, represented by cell 3 (Rcel.3). Each sample (0.5-5 kg) is a composite of three to five subsamples taken from sampling sites located 10-20 m apart. After sampling, the solid mining discharges collected were transported to the laboratory where it was crushed and then pulverized at 75 μm, before constituting final samples of 500 g. The dolomite samples were taken in Tiara in the west of the country, in the rural commune of Karangasso-Sambla, Houet province in the Hauts-Bassins region, approximately 38 km from Bobo-Dioulasso, the economic capital.

After the characterization of the mining discharges and dolomite samples, neutralization tests were carried out using columns 60 cm long and 15 cm in diameter.

In each column, mining discharge was introduced according to the granulometries: 8.38 kg of RS, 9.28 kg of RB, 12.91 kg of Rcel1 and 12.11 kg of Rcel3. Then, 2.62 kg of calcareous dolomite was deposited in each column above the mining discharges. Two liters of deionized water are added every 15 days to each column. The leachates at the outlet of the columns are collected at time intervals for analysis, for the

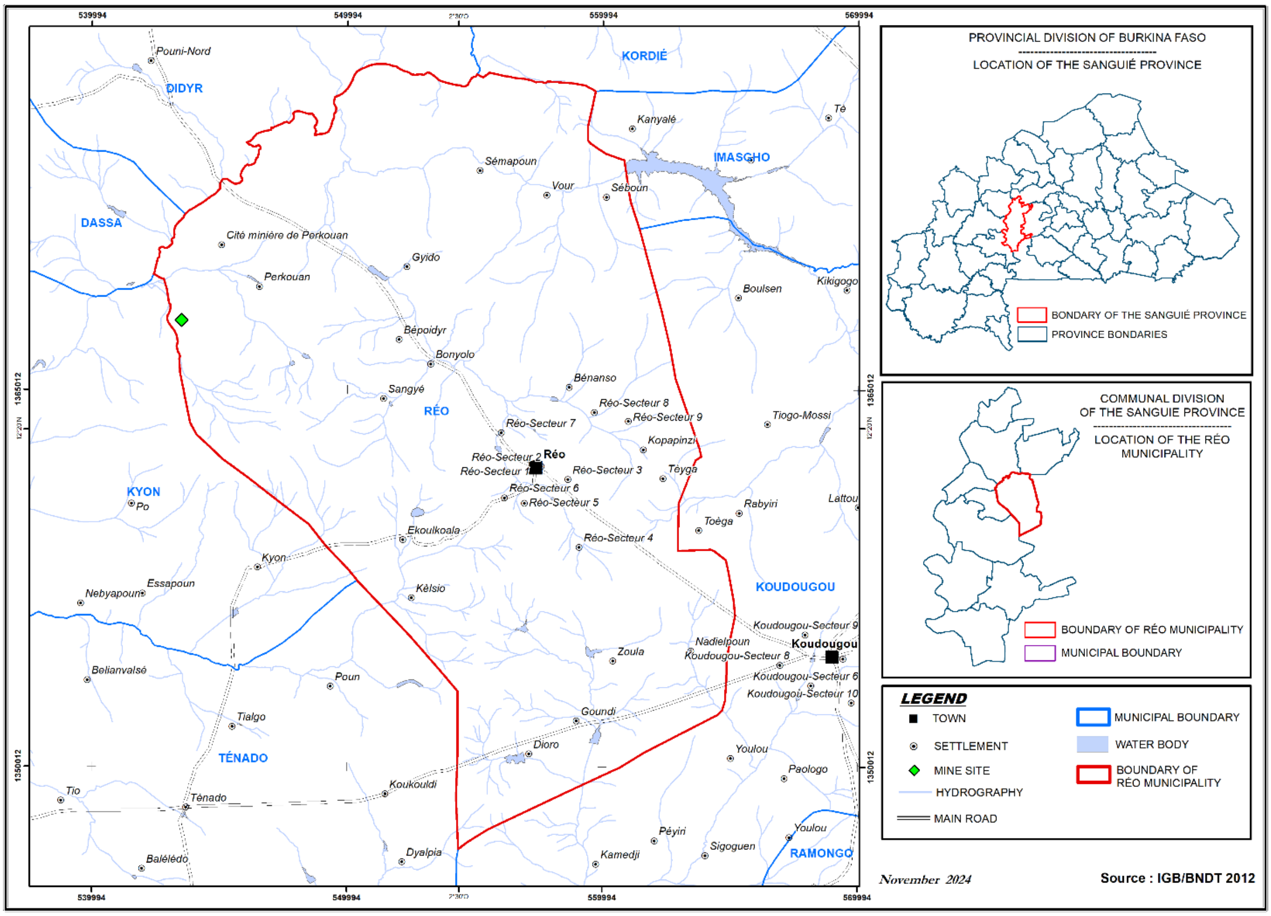


Fig. 1 Location of study area.

determination of certain physicochemical parameters (pH, electrical conductivity, metal contents). The experiment lasted 180 days (6 months).

After the neutralization test to assess the effectiveness of calcareous dolomite to directly buffer solid mining discharges samples, it was also necessary to assess its effectiveness on acidic (i.e. liquid) effluents. These acid effluents therefore represent acid leachates resulting from the kinetic test for predicting AMD on these mining discharges.

In fact, these mining discharges were subject to kinetic tests to predict AMD for 180 days, or six months, in parallel with the neutralization test. The leachates collected during these tests were subsequently used for neutralization tests using calcareous dolomite.

3. Results and Discussions

3.1 Granulometry of Mining Discharges

The mining residues (R.cel.1 and R.cel.3) have very little spread, heterogeneous and fine granulometries, continuous and similar to those of sands (Fig. 2). Their granulometry therefore covers the granulometric classes of fine sand (0.5 mm to 80 µm) and silt (80 µm to 2 µm). The discharges (RS and RB), very coarse, on the other hand present relatively spread and continuous granulometries.

Grain size is an important characteristic that influences the void ratio and porosity of mining residues. The particle size depends, among other things, on the mineralogy of the ore being mined, the degree of alteration of the ore, the grinding and separation or extraction process. It

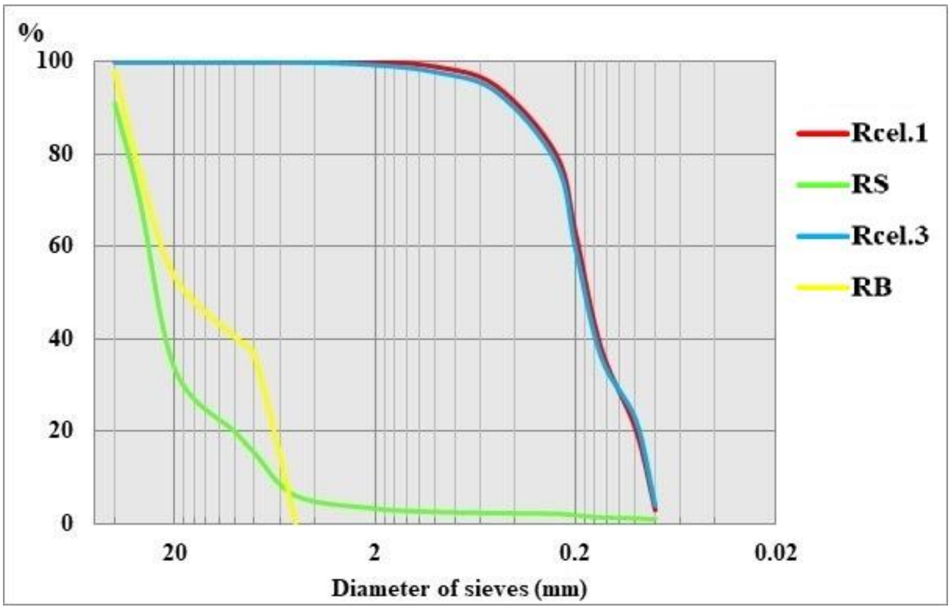


Fig. 2 Granulometric curves of mining discharges.

Table 1 Mineralogical composition of mining discharges (in percentages).

Mining discharges	RS	RB	Rcel1	Rcel3
Pyrite	0.3	3.5	42.1	27.3
Barite	0	0	12.7	3
Quartz	57.3	43.2	18.8	33.5
Chlorite	1	4.7	0.8	3.5
Epidote	2.7	8.8	1.8	0.7
Actinolite	2.1	11.4	8.7	3.8
Microcline	0.1	1.2	1.2	0
Plagioclase	3.3	11.1	4.4	6.6
Zircon	0	0.6	0.9	0.4
Almandine	0	0	0.4	0
Paragonite	9.8	0	0	0
Muscovite	23	15.3	1.4	13.7
Gypsum	0.1	0	0.5	0.2
Pyrrhotite	0.1	0	0.1	5.7
Rutile	0.1	0	0	0
Sphalerite	0	0.2	6.1	1.5

varies from one mine to another, within the same mine, as well as within the same tailings park.

Refs. [4, 10, 11] showed that metals tend to concentrate in the fine fractions, while the coarse fractions act more as diluting agents. The particle size therefore influences the water content, the void ratio and the hydraulic conductivity of the mining residues and consequently the physical and chemical stability (oxidation and generation of AMD).

Mining residues (R.cel.1 and R.cel.3) would therefore be very problematic given their very fine particle size and the chemicals used during the treatment process.

3.2 Mineralogical Composition of Mining Discharges

The mineralogical composition of the various mining discharges is recorded in Table 1 below. It shows that quartz is the most abundant mineral in all mining discharges, with, however, a predominance in waste rock (57.3%) and crusher rejects (43.2%). It also presents a relatively large proportion (33.5%) for what concerns the mining residues of cell 3 (Rcel3).

The proportions of muscovite are, as in the case of quartz, higher respectively at the level of sterile rejects (23%), the crusher (15.3%) and the mining residues of cell 3 (13.7%). Paragonite is present only in sterile rejects. Plagioclase, actinolite and epidote are relatively much more abundant in the crusher rejects with respectively 11.1%, 11.4% and 8.8%.

The results also show that the mining residues (Rcel1 and Rcel3) are those which contain the most sulfide such as pyrite and sphalerite. As for pyrrhotite, although the proportion is relatively high in the mining residues of cell 3 (Rcel3), its proportions are however identical (0.1%) in the mining residues of cell 1 (Rcel1) and in the waste rock. However, pyrrhotite is much more reactive than pyrite. It would oxidize between 20 and 100 times faster than pyrite [12, 13].

Since mining residues have the finest particle sizes, this confirms the fact that metals tend to concentrate in the fine fractions, while the coarse fractions act more as diluting agents [4, 10, 11]. The same applies to barite, which is a mineral with a high density, found only in mining residues. However, it should be noted that the mineralogy of the Perkoa zinc deposit is poor in acid-drinking minerals. Acidophilic minerals actually have an intrinsic neutralization potential due to their ability to react with and neutralize sulfuric acid [14].

3.3 Physicochemical Parameters of Mining Discharges

All mine discharges have an acidic pH (Table 2). Except for the pH of the crusher discharges (RB), all pH values do not comply with the standards in force in Burkina Faso. The electrical conductivity values are very high (198 to 550 times the standard in force in Burkina Faso). The pH and electrical conductivity values confirm that all mining discharges are problematic and therefore likely to generate AMD [15].

The contents of PHEs (Potentially Harmful Elements) are also recorded in Table 2. Arsenic, iron, lead and zinc have relatively very high levels.

For the mining residue of cell 1 (R.cel.1), the levels are significantly higher than the standards in force with the exception of cobalt and nickel for which the value is at the limit of the threshold value (50 mg/kg).

As regards cell 3 (R.cel.3), apart from cadmium (content below the detection limit), all other metals show values which are well above the standards in force. Regarding the crusher discharge (RB), only the cobalt content complies with the standards. For sterile discharge (SR), cobalt, copper and nickel have contents lower than the standards in force.

The high iron content of all mining discharges could be explained by the mineralogy of the deposit which is rich in pyrite (iron sulfide) and pyrrhotite (magnetic iron sulfide).

3.4 Dolomite

It is a whitish to grayish colored rock. Dolomite is composed mainly of dolomite (60.10%), talc (17.70%), calcite (9.40%), quartz (8.80%), vermiculite (3.50%) and, to a lesser extent, lizardite (0.40%). Dolomite has a spread grain size, and the majority of fragments have a size greater than 10 mm.

Table 2 Main physicochemical parameters of mining discharges.

	As	Cd	Cr	Co	Cu	Fe	Pb	Ni	Zn	pH	EC
Unity	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg		μs/cm
LD	1	0.1	0.2	0.5	2	5	1	0.5	1	--	--
RS	915	14	69	< LD	35	56,421	4,240	20	1,306	4.81	396
RB	504	35	310	19	69	55,351	2,322	59	6,071	5.88	682
Rcel.1	491	150	270	< LD	74	210,169	1,335	50	50,664	4.1	1,101
Rcel.3	537	< LD	120	27	174	196,623	583	51	14,689	4.66	745
Quality standard	20	1	75	25	50	5	100	50	200	5.5-8	2

This rock, commonly called dolomitic limestone [16], would rather be calcareous dolomite with more than 50% dolomite in its mineralogical composition. In fact, calcareous dolomite is a carbonate rock that contains between 50% and 95% dolomite and 50% to 5% calcite [17]. However, it is not pure dolomite given the dolomite content (60.10%).

The pH is 8.51, which confirms the alkaline nature of the rock and therefore its potential capacity to buffer (neutralize) oxidized mining discharges or acidic effluents (leachates).

The electrical conductivity of 80.60 µs/cm, attests to the very low quantity of dissolved matter as shown by the mineralogical composition.

3.5 Neutralization Tests on Mining Discharges

The four mining rejects (RS, RB, Rcel1 and Rcel3) were used for neutralization tests with calcareous dolomite. Samples were taken to monitor changes over time in certain parameters such as pH, electrical conductivity and metal content.

3.5.1 Evolution of pH over Time

The pH values measured as a function of time (Fig. 3) show that all mining discharges are initially oxidized and acidic. Only for sterile discharges (SR), there is a progressive increase in pH up to the value of 7.08 (therefore neutrality) on the 135th day and 7.18 on the 150th day. This latter value will be maintained until the end of the tests (Fig. 3). As for the crusher discharges (RB), the pH values changed very little and always remained around 2 with a final value of 2.49 at the end of the experiment. The same observation can be made at the level of the mining residue Rcel1 where the maximum value reached is 2.51. As for the Rcel3 mining residue, the pH showed a progressive increase from the beginning to reach the value of 6.31 on the 90th day and then started to decrease progressively again, with a very acidic final value of 2.40.

In short, the neutralizing power of calcareous dolomite is effective only with sterile discharges (SR) for which the pH increases progressively beyond even the threshold value of 6.5, on the 60th day.

At the Rcel3 mining residue level, the pH increased progressively until the 90th day without reaching the acceptable limit value of 6.5. This is probably due to a decrease in the reactivity of the calcareous dolomite and therefore its effectiveness from this date. In effect, this reaction causes precipitation and the formation of a thin film which will coat the fragments of the rock and lead to a reduction in its reactivity and therefore its effectiveness.

Generally speaking, apart from sterile discharges, the neutralization process did not allow the value of 6.5 to be reached, which is the standard in force for pH in Burkina Faso. It should also be noted that Rcel1 and Rcel3 are the finest and most acidic rejects, unlike RS and RB which are much coarser. This would confirm the fact that the granulometry would therefore

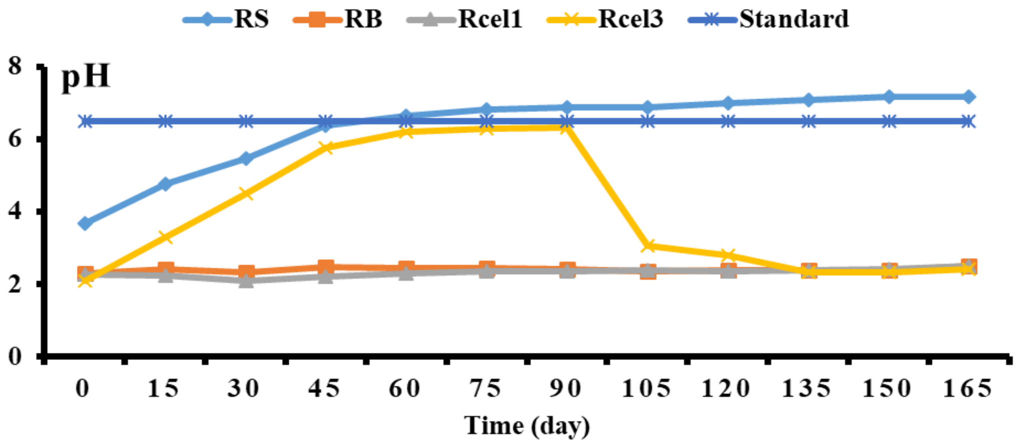


Fig. 3 Evolution of pH over time.

influence the water content, the void index and the hydraulic conductivity of the mining discharges and consequently the physical and chemical stability (oxidation and generation of AMD). The Rcel1 and Rcel3 mining residues that come from the processing plant and are stored in the mining tailings park are the most problematic, because in addition to their fineness they would also contain the chemicals used in the treatment process to recover the zinc.

3.5.2 Evolution of Electrical Conductivity over Time

The electrical conductivity values measured during the neutralization test (Fig. 4) show a considerable drop from the first 15 days. This drop is much more pronounced at the level of sterile discharges (more than a third) and mining residues with for Rcel1, more than a quarter and for Rcel3 more than half.

Regarding waste rock, there is a gradual decrease in electrical conductivity until the 150th day, then a slight increase on the 165th day.

As for the crusher rejects, from the 60th day, the electrical conductivity began to increase again, only to decrease on the 75th day. At the end of this date, we see once again an increase in the value of electrical conductivity until the 120th day. It will then undergo a progressive decrease until the end of the experiment.

As for the Rcel1 mining residues, the electrical conductivity evolves in sawtooth patterns between the 15th and the 60th day, to start to increase until the 120th day. It will subsequently decrease, and at the end of the test, a slight increase.

The electrical conductivity at the mine tailings (Rcel3) decreased gradually, then began to increase from the 90th day.

However, until the end of the experiment, only the value of the electrical conductivity of the waste rock is lower than the standard in force in Burkina Faso which is 1,000 µS/cm. This allows us to state that calcareous dolomite is only effective in neutralizing sterile discharges, also confirming what is observed in terms of the evolution of pH.

As in the case of the evolution of the pH, that of the electrical conductivity also shows that during the test we note a drop in the reactivity of the limestone dolomite, which results in an increase at times in the electrical conductivity.

3.5.3 Evolution of the Content of PHEs over Time

Fig. 5 below shows the evolution of PHEs over time. It shows that for all PHEs, the levels dropped considerably from the 15th day. Regarding arsenic and lead, the levels at the end of neutralization for all mining discharges are lower than the standards in force in Burkina Faso. Cadmium levels at the end of the test for waste rock, crusher rejects and Rcel1 mining residues remain above current standards. Cadmium levels in Rcel1 mining residues increase from the 60th day and will begin to decrease thereafter without being below the threshold value. Those of chromium and nickel for discharge from the crusher and Rcel1 mining

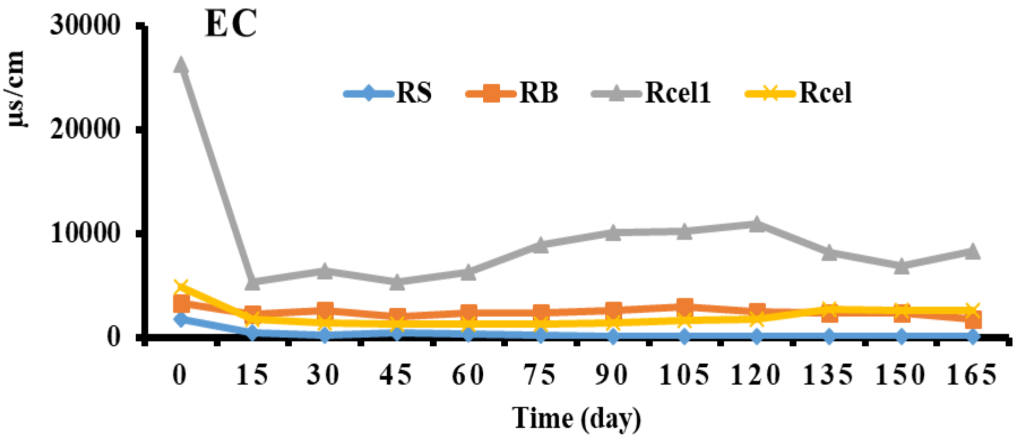
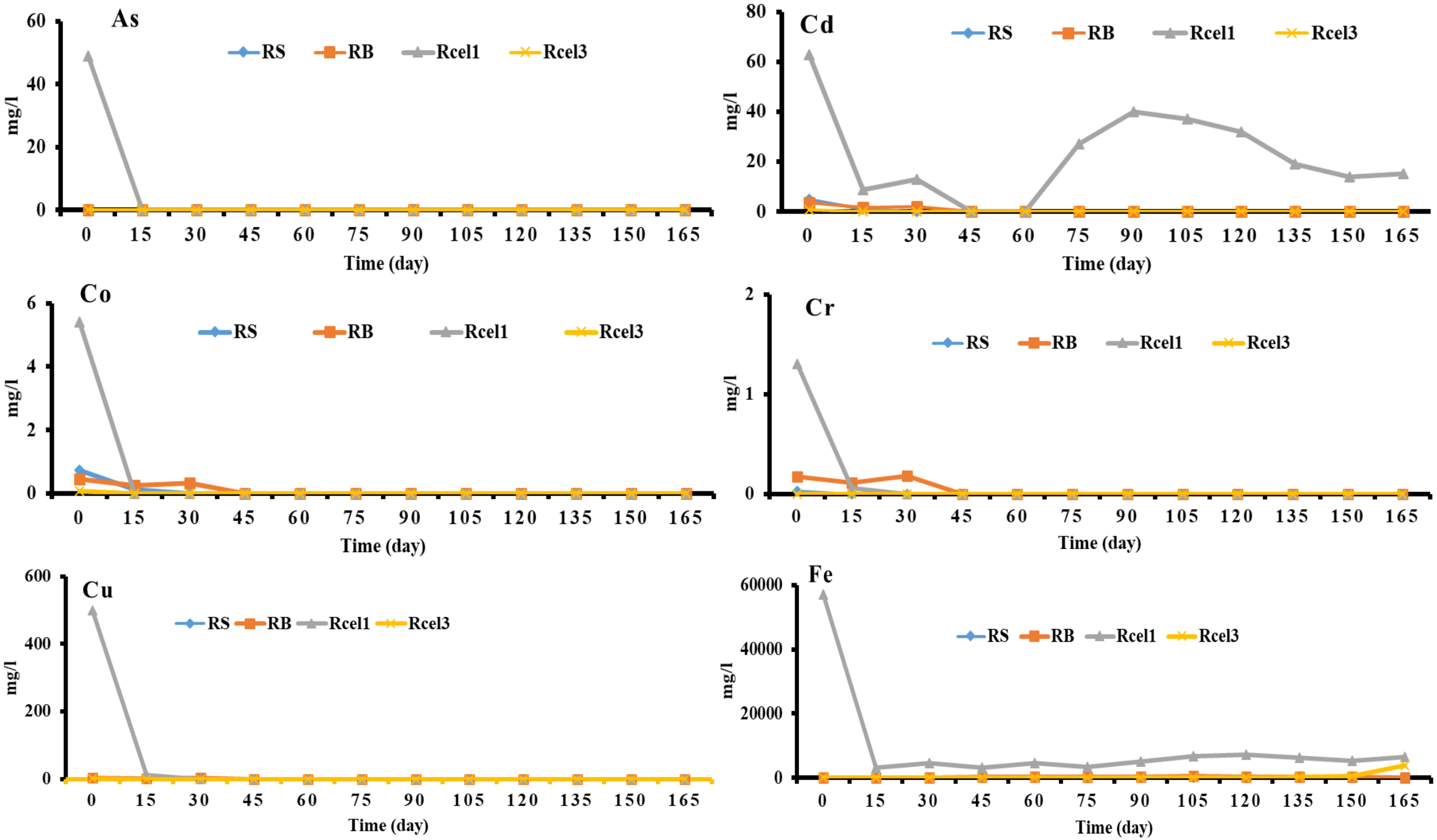


Fig. 4 Evolution of electrical conductivity over time.


As
Cd
Co
Cr
Cu
Fe
RS
RB
Rcel1
Rcel3
mg/l
Time (day)
0
15
30
45
60
75
90
105
120
135
150
165
60
40
20
0
80
6
4
2
1
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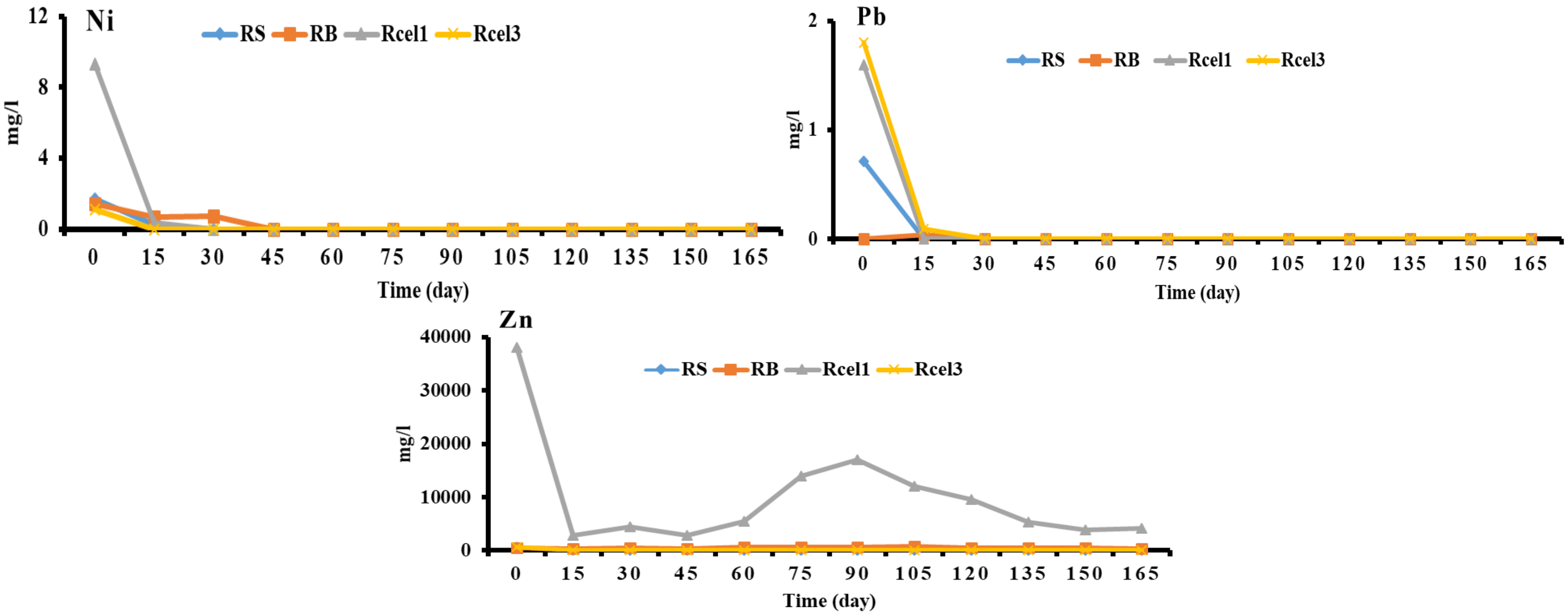

Fig. 5 Evolution of the content of PHEs over time.

residues remain above standards. As regards cobalt and copper, only the contents for crusher rejects and Rcel1 mining residues respectively remain above the threshold values.

In relation to iron and zinc, the contents at the level of crusher rejects and mining residues Rcel1 and Rcel3 remain higher than the standards in force in Burkina Faso. The evolution of zinc in the case of Rcel1 mining residues is practically similar to that of cadmium.

These results show that for the waste rock, with the exception of cadmium, the contents of the other PHEs at the end of neutralization comply with the standards in force. Neutralization by calcareous dolomite is effective in the precipitation of arsenic and lead.

In summary, calcareous dolomite is effective for the neutralization of sterile discharges (SR) and the precipitation of PHEs contained therein. These sterile discharges are already oxidized and acidic with a pH of 4.81, and are therefore potentially generators of AMD. This chemical instability could also cause physical instability, in addition to environmental and health damage.

The installation of a multi-layer covering (sometimes called a dry barrier) is recognized as a technique, one of the functions of which would be to limit the production of acid [1, 18-20]. Given the effectiveness of calcareous dolomite in buffering the pH of waste rock from the Perkoa zinc mine, it could be used to limit the production of AMD from these waste rocks and possibly in the rehabilitation of mining waste rock piles.

3.6 Acid Leachate Neutralization Tests

The acid leachates were placed in contact with the calcareous dolomite for three weeks. The samples taken at time intervals were analyzed to evaluate the evolution of pH, electrical conductivity and certain PHEs as a function of time.

3.6.1 Evolution of Leachate pH over Time

The evolution of pH over time is shown in Table 3. It shows that after only one day of contact, the initially very acidic pH values increased significantly (they practically doubled or tripled).

The pH values of the sterile discharges, from the first day (7.26) exceeded the recommended threshold value of 6.5.

As for the crusher rejects (RB) and mining residues (Rcel1 and Rcel3), on the 12th day, the pH values of 6.56, 6.51 and 6.57 respectively, are slightly higher than the limit value of 6.5. From the 17th day, those of the crusher rejects will relatively decrease and be slightly below the threshold value. As regards the Rcel3 mining residues, the pH will fluctuate from this date but will remain in line with the limit value at the end of the experiment.

In summary, these results show that calcareous dolomite is effective in neutralizing acid leachates from various mining discharges. It therefore has a neutralization potential capable of buffering the pH of the leachates from these four mining discharges.

3.6.2 Evolution of the Electrical Conductivity of Leachate over Time

The evolution of electrical conductivity over time varies greatly depending on the leachates from mining discharge (Table 4).

For leachates from sterile discharges, the electrical conductivity value more than doubled from the first day. It continued to grow thereafter, even reaching triple the initial value. From the 12th day it will decrease slightly until the end of the test. However, the final value of electrical conductivity (348 µS/cm) for these sterile discharges is significantly lower than the limit value of 1,000 µS/cm.

For leachates from crusher discharges and Rcel1 mining residues, electrical conductivity values gradually decreased over time until the end of the experiment, but always remained above the standard of 1,000 µS/cm.

The values of the electrical conductivity of leachates from Rcel3 mining residues have evolved in a sawtooth manner, with sometimes decreases and sometimes increases. The value at the end of the test (2,124 µS/cm) remains, however, higher than the standard in force.

Table 3 Evolution of leachate pH over time.

	Leachate			
Time (day)	RS	RB	Rcel1	Rcel3
	pH values			
0	3.83	2.34	2.39	2.46
1	7.26	6.3	5.91	6.5
4	7.26	6.34	6.17	6.32
6	7.15	6.38	6.39	6.46
7	7.25	6.49	6.44	6.46
11	7.13	6.49	6.45	6.47
12	7.23	6.56	6.51	6.57
14	7.21	6.59	6.51	6.5
17	7.23	6.53	6.48	6.55
21	7.08	6.47	6.43	6.49
23	7.04	6.39	6.48	6.54

Table 4 Evolution of the electrical conductivity of leachate over time.

	Leachate			
Time (day)	RS	RB	Rcel1	Rcel3
	EC values (μS/cm)			
0	123	2,250	5,040	3,510
1	272	2,167	3,340	2,400
4	393	2,142	2,059	2,136
6	449	2,132	1,976	2,105
7	439	2,109	1,953	2,102
11	425	2,101	1,953	2,140
12	396	2,085	1,950	2,144
14	382	2,044	1,947	2,139
17	362	2,013	1,942	2,128
21	359	1,993	1,942	2,134
23	348	1,959	1,937	2,124

As in the case of the neutralization of solid mining discharges, calcareous dolomite is effective only in the neutralization of leachate resulting from waste rock, with regard to electrical conductivity.

Kagambega et al. [4, 21] using high purity, very alkaline dolomite with a pH of around 9.40 and a homogeneous composition, i.e. almost exclusively made up of dolomite (96.7% dolomite, 2% quartz and 1.3% calcite) showed that this material was effective in neutralizing heavily contaminated mine drainage from the Eustis and Val d'Or mines in Canada.

Several factors influence the effectiveness of dolomite in neutralizing acid mine drainage [4, 8, 9, 21]. These mainly concern the mineralogy of the dolomite, the contact time of the dolomite with the AMD, the initial acidity and the nature of the AMD.

The mineralogy of dolomite would therefore be a very determining parameter in the neutralization process. If the dolomite used in the case of the neutralization of AMD from the Eustis and Val d'Or mines in Canada was of very high purity, the same is not true of that used in the present study which has a composition of calcareous dolomite with only 60% dolomite, which could explain the results of neutralization of solid mining discharges obtained.

Chemical reactions occur between dolomite and AMD once these materials are brought into contact. These chemical reactions lead to the formation of precipitates and therefore deposits on the surfaces of the dolomite fragments [4, 8, 9, 21]. These deposits therefore reduce contact and consequently reactivity. For this reason, in the AMD treatment system, through the limestone drains, the limestone materials are usually renewed to increase their efficiency.

Furthermore, the acidity, nature and composition of AMD that influence neutralization are dependent on the nature and composition of the mineral deposit. The higher the acidity, the more metals are solubilized in the AMD, which can affect the neutralization capacity of dolomite [4, 8, 9, 21]. The Perkoa deposit is a stratiform hydrothermal mineralization of volcanogenic massive sulfide type with zinc, lead and silver. This mineralization contains sphalerite (zinc sulfide), pyrite (iron sulfide), pyrrhotite (magnetic iron sulfide) and, incidentally, galena (lead sulfide) more or less argentiferous, contained in a matrix of quartz and barium sulfate [22]. The mining discharges also naturally had very high metal contents, which could be a parameter that would negatively influence the neutralization process.

4. Conclusion

Calcareous dolomite is very effective in neutralizing oxidized and acidic steriles discharges from the Perkoa zinc mine and precipitating PHEs contained therein. It is less effective on crusher rejects and mining residues.

However, limestone dolomite is very effective in neutralizing acidic leachates resulting from four mining discharges and precipitating PHEs contained therein.

Calcareous dolomite could therefore be used in the rehabilitation of the mining waste dumps of the Perkoa zinc mine, which has been closed since 2022.

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