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ENVIRONMENTAL PROTECTION AGAINST ACID MINE DRAINAGE (AMD) TESTING OF SULPHIDE MINING WASTE ENRICHMENT OF THE CHAABET-EL-HAMRA MINE (ALGERIA)

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Abstract: The mining waste from the Chaabet-El-Hamra mine contains sulfides such as pyrite (FeS_2), galena (PbS) and chalcopyrite ($CuFeS_2$) Which pose a threat to the environment. Sulphide minerals under the effect of oxygen and in the presence of water cause a phenomenon of acid mine drainage. Samples taken at the site of the sulphide mine waste at the Chaabet El Hamra mine and subsequently subjected to chemical analyzes offered an average sulfur content of 9%. X-ray diffractometer analyzes confirm the presence of a considerable inclusion of pyrite containing secondary minerals of sphalerite, and galena. To do this, the tests were directed to an environmental desulphurization process by flotation of the pyrite-rich fraction with depression of the low sulfur mineralogical matrix containing heavy metals of zinc and lead.

Keywords**:** *mining waste, sulphide ores, AMD, characterization, environmental desulfurization, flotation, environment*

1. INTRODUCTION

The most important environmental impact of its mining waste is the mobility of metallic trace elements that pose a major risk to the soil, water and air environment (Consas et al. 2005). These types of mining waste contain a complex mineralogical composi-

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tion of pyrite, marcasite, and other sulphide minerals of zinc, lead, copper and arsenic. The recoverable elements are at average contents of 0.5% Cu and 1.38% Zn. They can be recovered by mineralurgical processes such as gravimetric classification, magnetic separation, flotation or by leaching (Kitobo 2009).

According to (Plante et al. 2015) The tools developed for acid mine drainage (AMD) prove ineffective in predicting the geochemical behavior of tailings rock with significant chemical sorption capacity, delaying the onset of contaminated neutral drainage (CND), one research study (Kitobo, Kalenga, Ilunga, Luboya, O.J., 2007), all these wastes were placed without any prior treatmentin storage areas located on the surface. However, their physical and chemical instability has a negative impact on the surrounding environment such as natural rivers, underlying soils and groundwater through the migration and dispersion of metal trace element like arsenic, cadmium, cobalt, copper, lead, zinc.

In the case of Chaabet-El-Hamra mine exploitation and sulphide ores of zinc processing, it is likely a generation of acid mine drainage in the dike due to the presence of pyrite and some sulphides residual, a new technique for environmental desulfurization (selective flotation) is then used to recover the fraction of sulphide minerals contained in waste treatment (Benzaazoua et al. 2003; Kongolo et al. 2004; Bois et al. 2005; Mermillod 2005) and (Mermillod 2002) find Generating acidity right out of the processing circuit and before the tailings deposit, due to restrictive and high social conscience regulations, The prediction of water quality in the mine drainage is of utmost importance for the environment (Blowes et al. 2003; Benzaazoua et al. 2004; Villeneuve et al. 2009; Plante et al. 2012; Bouzahzah et al. 2014).

To counter this problem of AMD, a new technique of environmental desulphurization or (selective flotation) is used to recover the fraction of sulphide minerals contained in the treatment rejects, generating acidity as soon as they leave the treatment circuit and before their deposition To the tailings park (Benzaazoua et al. 2000), (Benzaazoua et al. 2003).

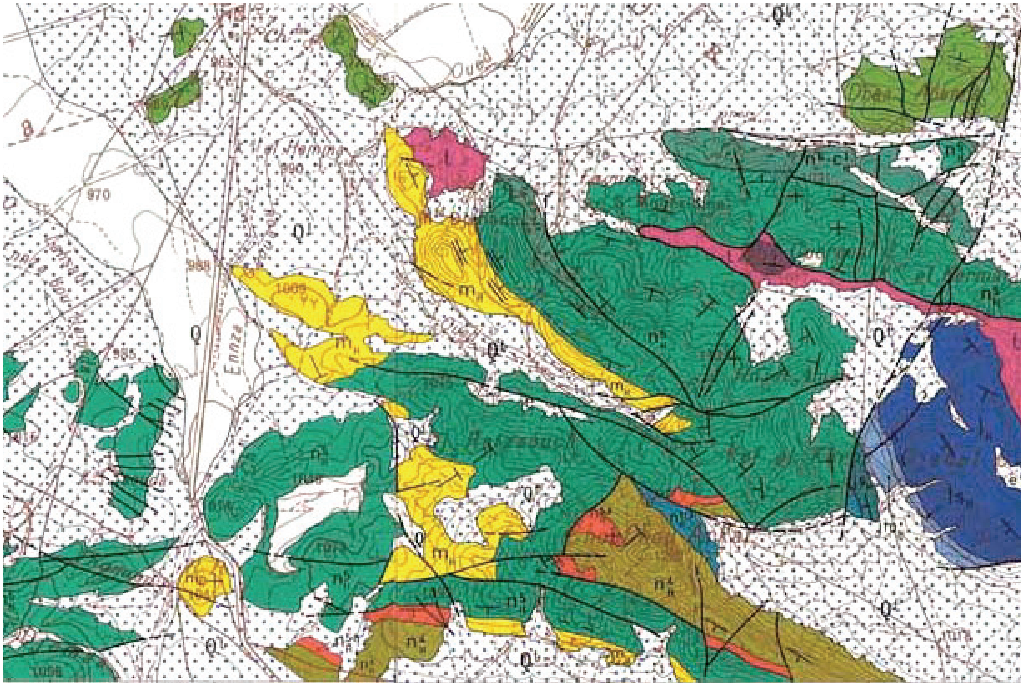
(Bolduc Frédérick 2014) analyzes the drainage effects of the construction of sterile rock inclusions (IRS) inside a tailings pond is an alternative disposal technique that aims at better management of mining discharges. This technique consists of strategically placing the IRS inside the tailings pond, at the beginning and during its operation, so as to form compartments (or cells) in which the residues are stored.

Thomas et al. (2012) and Genty (2012) tested the height iron acid mine drainage by using eight different sulphate reducing passive bio-reactor SRPB in batch and column tests. This study defines a process for the industrial processing of these releases that meets environmental protection requirements. In this context, testing flotation sulphur emission has been conducted for the recovery of the fraction rich in sulphide (pyrite, marcasite).

At the mining and environment recovery laboratory, flotation tests of sulphide mining were carried out for the recovery of the sulphide-rich fraction (pyrite, marcasite) compared to the remaining sulfur-poor rejects containing also metals Heavy with zinc, copper and arsenic.

2. GEOLOGICAL OVERVIEW OF THE MINERALIZATION OF THE CHAABET-EL-HAMRA DEPOSIT

The Chaabet-El-Hamra deposit is part of the metallogenic district of the Hodna Mountains, which contains large Pb-Zn mineralization located in the Ain Azel region



A Recent or current alluvial deposits, Q^1 Polygene glacis coating reliefs.

n_H^5 Aptian: limestones with Orbitolines, dolomites n_H^{5a} Aptian with predominantly marly.

m_H Miocene: conglomerates, oyster marls and sandstone limestones.

c_H^{1-2} Upper and Turonian Cenomanian: dolomites and limestones with flint or miliolids.

n_H^4 Barremian: dolomites, limestones and sandstones.

t Trias: variegated marls with brecciated gypsum, calcaro-dolomitic (dl) and ophite (ω)

n_H^{1-3} Neocomian: sandstones, pelites, marls to Amonites and Brachiopods.

js Upper Jurassic: fine limestones at Saccocomidae, biomicrites at Calpionelles and Pygopes.

jm Middle Jurassic: Varicolorous limestones at Belemnites.

ls Lias superior marly to Ammonites. l Solid Carbonate Lias

Fig. 1. Location of the Chaabet El-Hamra Mine (Sonatrach 1977)

of the setif wilaya (Algeria). The mineralization of this Chaabet-El-Hamra deposit is observed in bundles in the form of mineralized lenses of composition sometimes monomineral, sometimes mixed. It is mainly represented by sphalerite, pyrite, marcasite, galena encountered rarely and therefore of no industrial importance. The secondary minerals are hematite, calcite, barite, dolomite and more rarely quartz and gypsum. The oxidation minerals are mainly smithsonite, cerusite and limonite.

The mineralization of pyrite, marcasite, blende and rarely galena is intimately related to the Hawaiian dolomitic rocks, independently locating to the tectonic structures affecting this level bearing mineralization. The zinciferous mineralization occurs in lenticular layers, grouped in two stratiform bundles, separated by the sterile whitish dolomite bank of 6m of power. Galena is very rare and usually develops at the ends of the lenses, limiting the zinc zone to the pyritic zone. Sphalerite occurs in several forms: massive, cracked, and breccia, which is mainly industrial ore (Fig. 1). Shows the geological section of the Chaabet-El-Hamra mine.

3. ENRICHMENT OF THE SULPHIDE ORE OF CHAABET-EL-HAMRA: FLOTATION OF THE SPHALERITE (ZNS) WITH GANGUE OF PYRITE AND DOLOMITE

Recovery of a zinc concentrate requires a number of mineral processing operations, the purpose of which is to reduce the size of the ore to the release of the zinc particles relative to the gangue to separate the mineral particles Zinc with respect to the gangue.

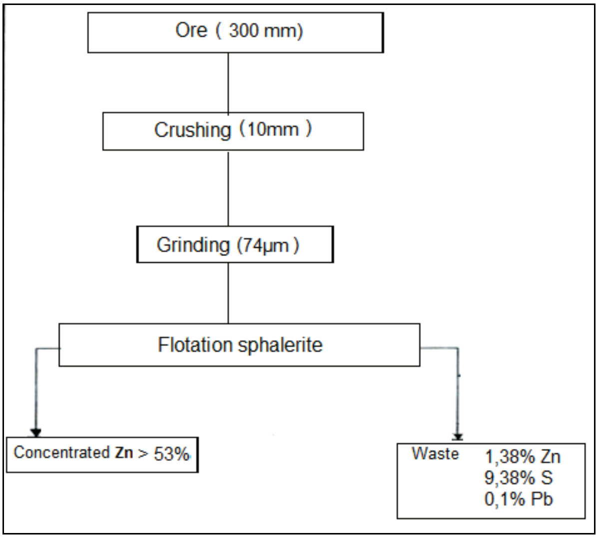


Fig. 2. General scheme of flotation of the sphalerite (ZnS) with pyrite depression

The ore is processed by wet grinding by means of a ball mill. The crushed ore at 74 µm is subjected to a zinc flotation preceded by stirring in order to allow the copper sulphate to activate the free grains of the zinc mineral after addition of the potassium amylxanthate as a collection of sphalerite minerals (Fig. 2).

- The main flotation circuit consists of a roughing bench (9 cells) and a bench (9 cells);
- The lifting circuit is realized by three (03) stages of flotation with 9 cells.

The concentrate obtained by means of 53% Zn, on the other hand, the rejects contain minerals of pyrite, sphalerite and a negligible quantity of the galena. These sulphide mine wastes actually pose environmental problems related to mine release sites (mainly concentrator discharges and tailings) are associated with the chemical and physical stability of the wastes. The chemical stability of the discharges will be compromised when the interaction between the water and the discharge creates contamination that causes acid mine drainage to the presence of sulphide mine discharges (Fig. 3).

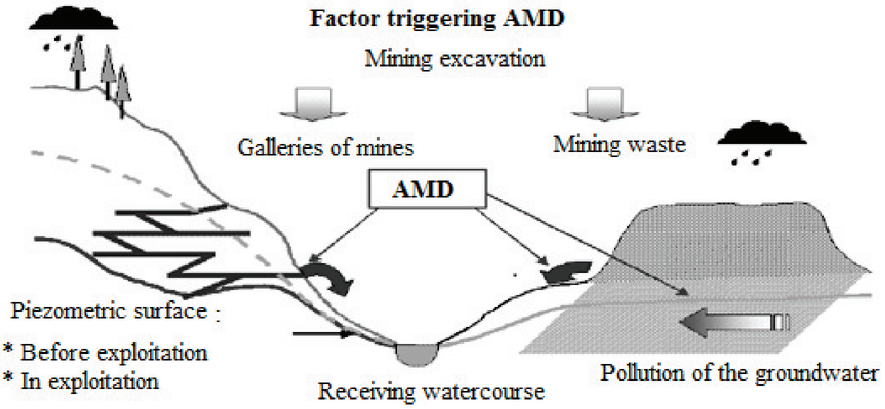


Fig. 3. General scheme of operation of mines and their impact on groundwater and surface water (Bounouala et al. 2000; Bounouala et al. 2001)

However, sulphide mine wasts are residues that generate acidity. The potentials of acidity and neutralization are generally expressed in kg of $CaCO_3$ in ton of wast. The main traditionally neutralizing minerals are carbonates and some silicates: anorthite, olivine, forsterite. The equilibrium between PA and PN is at the origin of the classification of the treatment rejects according to their acid generating potential. The balance between the PA and the PN can be calculated in two ways: via the difference between PN and PA, ie the net neutralization potential PNN = PN-PA, or via the ratio between PN and PA, or the net neutralization potential PNN = PN/PA

If PN-PA> 20 kg $CaCO_3$/t, the wasts are not acid generators.

If PN-PA <–20 kg $CaCO_3$/t, the wasts are acid generators.

If PN-PA is between –20 and 20 kg $CaCO_3$/t, the wasts are in an uncertainty zone;

Kinetic percolation tests in columns are then necessary. And according to the other PN/AP classification criterion:

PN/PA > 2, non-generating wasts

PN/PA < 1, generating wasts

PN/PA between 1 and 2, wasts in the uncertainty zone. (Qubec Expertise Center, 2006)

In the case of a study on Chaabet El Hamra's mine wastes, the PN/PA report confirms that these wastes generate acidity.

$PA = 0.015 \times 31.25 = 0.46$ Kg $CaCO_3$/t

$PN = 1.33 \times 50/600 = 0.11$ Kg $CaCO_3$/t

$PN/PA = 0.11/0.46 = 0.23$ Kg $CaCO_3/t < 1$ so our wastes are generators.

3. MATERIALS AND METHODS

3.1. LEVY AND SAMPLING

A 50 kg sample taken from the dike site of Chaabet-El-Hamra is subjected to homogenization and then quartering to reach a representative sample of 600 g. This sampling procedure is carried out by the mesh sampling method (Fig. 4), the objective is to identify the physicochemical and mineralogical parameters and to highlight their intrinsic properties which determine their behavior and their impact on the environment.

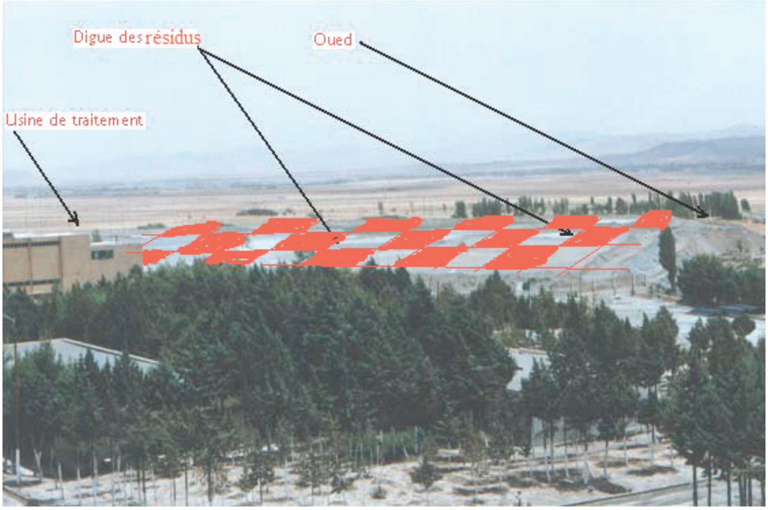


Fig. 4. Conventional sampling plan (sampling points are in red)

To do this, a sample is subjected to a particle size analysis carried out on a Ritscher sieving machine. The results obtained are presented in the diagram of (Fig. 5).

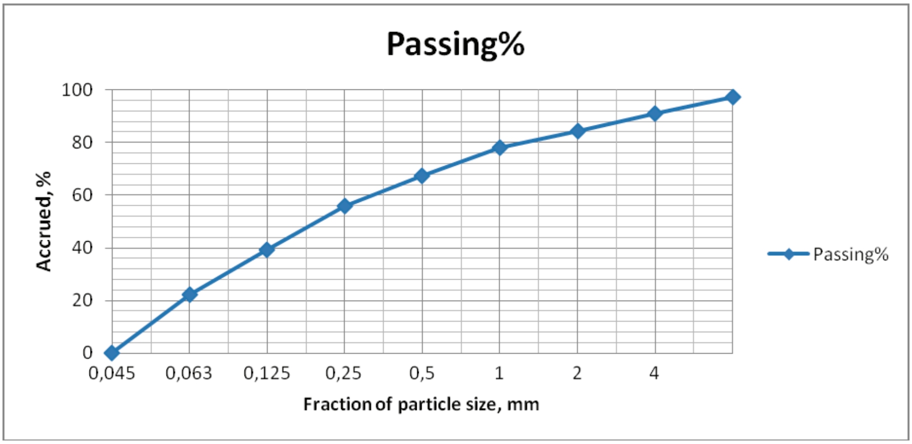


Fig. 5. Curve of the particle size distribution of sulphide mining waste from the Chaabet-El-Hamra dam

According to the granulometric curve, it is observed that more than 80% of the particles of the mining waste are less than 1 mm, which has a homogeneous population.

3.2. PHYSICO-CHEMICAL CHARACTERIZATION OF MINING WASTE

The identification of the crystallized mineral phases was carried out by X-ray diffraction (XRD) using a Bruker diffractometer model D8 operating under reflection at the Kα1 incidence of cobalt and equipped with a scintillation detector. The preparation was made in the form of a disoriented powder in order to reduce the phenomena of preferential orientation. This type of preparation favors the interaction between the incident beam and a greater number of crystallites, which makes it possible to better

Table 1. Mineralogical composition of the particle size fractions of the Chaabet-El-Hamra mining waste

Fraction of particle size (mm)	Chemical and mineralogical composition of releases
>4	Marcasite (FeS_2), Realgar (AsS), covellite (CuS)
–4 + 2	Marcasite (FeS_2), Realgar (AsS), bornite (Cu_5FeS_4)
–2 + 1	Marcasite (FeS_2), Realgar (AsS), sphalerite (ZnS)
–1 + 0.5	Marcasite (FeS_2), Anglesite ($PbSO_4$), chalcocite (Cu_2S)
–0.5 + 0.25	Marcasite (FeS_2), chalcopyrite ($CuFeS_2$)
–0.25 + 0.125	Marcasite (FeS_2), Greenockite (CdS), bornite (Cu_5FeS_4)
–0.125 + 0.63	Marcasite (FeS_2) chalcopyrite ($CuFeS_2$) Linnaeite (CoS) sphalérite (ZnS) chalcocite (Cu_2S)
–0.63 + 0.45	Marcasite (FeS_2) chalcopyrite ($CuFeS_2$) covellite (CuS) chalcocite (Cu_2S)
<0.45	Marcasite (FeS_2) Molybdenite (MoS), Greenockite (CdS), Covellite (CuS),

account for all the phases present in the sample (Fig. 6). The main observations by XRD are summarized in (Table 1).

According to Table 1, it is found that all granulometric fractions contain, in the majority of cases, marcasite, pyrite and sphalerite.

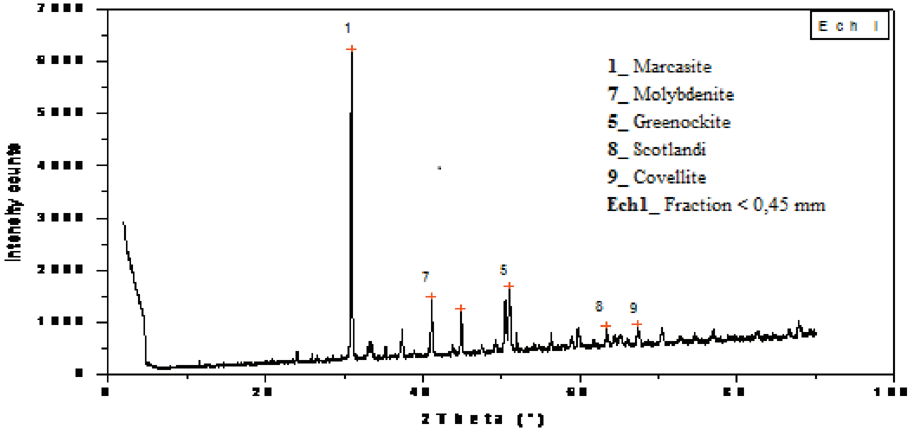


Fig. 6. Spectrum of the mineralogical composition of the fraction less than 0.45 mm

Chemical analyzes of the discharges were carried out by Atomic Absorption Spectrometry (AAS) dissolved in hydrochloric acid (HCl) preceded by a melting with sodium peroxide (Na_2O_2), the results obtained are presented in (Table 2).

Table 2. Chemical analysis of the releases of Chaabet-El-Hamra

Zn	Fe	S	Ca	Cu	Pb	Cd	As	K	Na	Mg	CO_2	SO_4^{-2}
1.38	8.75	9.33	16.49	0.50	0.09	0.02	0.03	0.40	2.69	2.69	6.73	12.66

Table 3. Requirements at the final effluent discharge point

Parameter	Medium concentration acceptable monthly	Maximum concentration acceptable
Extractable Arsenic	0.2 mg/l	0.4 mg/l
Extractable copper	0.3 mg/l	0.6 mg/l
Extractable iron	3 mg/l	6 mg/l
Extractable Nickel	0.5 mg/l	1 mg/l
Extractable lead	0.2 mg/l	0.4 mg/l
Extractable Zinc	0.5 mg/l	1 mg/l
Total cyanides	1 mg/l	2 mg/l
Hydrocarbons (C10–C50)	1 mg/l	2 mg/l
Suspended matter	15 mg/l	30 mg/l

In view of these results, Chaabet-El-Hamra mining discharges carry heavy metals (Cu, Cd, As, Pb) and zinc have a high value. The sulfur content of 9% is likely to present a probable risk of acid mine drainage (DMA) in the presence of surface water and surface water flow. However, the Canadian guideline (019) relating to mining and the environment, ETM concentrations should not exceed the following values (Table 3).

3.3. FLOTATION OF SULPHIDE MINING WASTES (ENVIRONMENTAL DESULFURIZATION)

Environmental desulfurization is a new process used in the mining industry to recover the sulfur-rich fraction (Fig. 7). The steps of preparation of the pulp preceding flotation were carried out in a Denver flotation cell of 2.5 l capacity and with stirring at 1200 rpm for conditioning the pulp for 20 min and then adding (H_2SO_4) diluted to Maintaining an acidic medium. The variation of the pH is achieved by adding sulfuric acid with a concentration of 98%, i.e., 800 to 1200 g/t, and the collector potassium amylxanthate at 50 to 150 g/t, in each case a parameter is varied in the flotation test lasted 12 minutes. Five concentrates were recovered after 2, 5, 8, 10 and 12 minutes of flotation (C1, C2, C3, C4 and C5), Concentrated and the residues are dried in an oven at 100 °C, weighed and then homogenized and finally analyzed by Atomic Absorption Spectrometry.

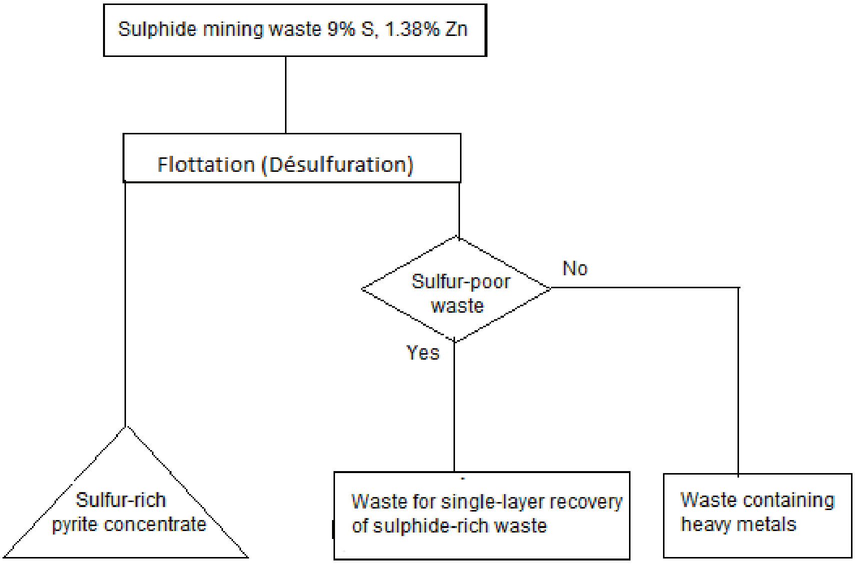


Fig. 7. Treatment and Management Diagram of Sulphide Mining wastes

4. RESULTS AND DISCUSSIONS

The pyrite contained in the sphalerite flotation waste is first reactivated by sulfuric acid and then floated to an acidic pH. In order to determine the optimum conditions of the medium, the acid quantities (H_2SO_4) were varied from 800 to 1200 g/t, which made it possible to vary the pH from 10 to 5 (Fig. 8).

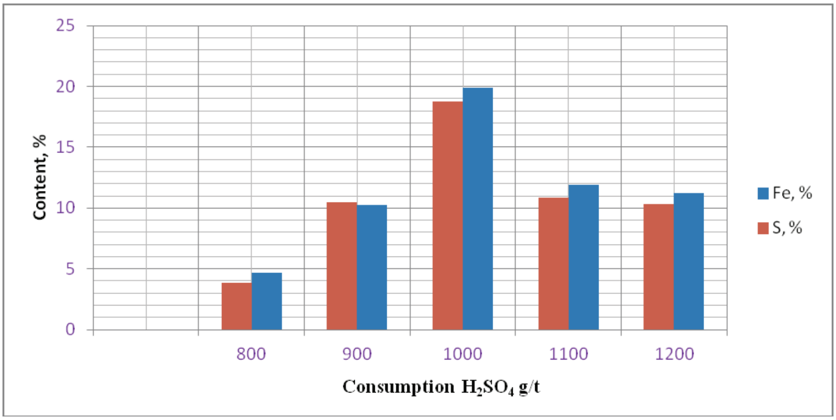


Fig. 8. Effect of H_2SO_4 consumption on the recovery of sulfuric pyrite

The addition of the acid leads to the decrease of the pH until reaching the value of pH 5 Which corresponds to an addition of 1000 g/t of concentrated sulfuric acid (98%) in the suspension, i.e., a content of 20% Fe versus 19% sulfur. Collectors are organic products whose molecule consists of a polar part that attaches to the surface of the particle, the nonpolar-polar part repels water and allows the fixation of air bubbles on this surface (hydrophobicity)

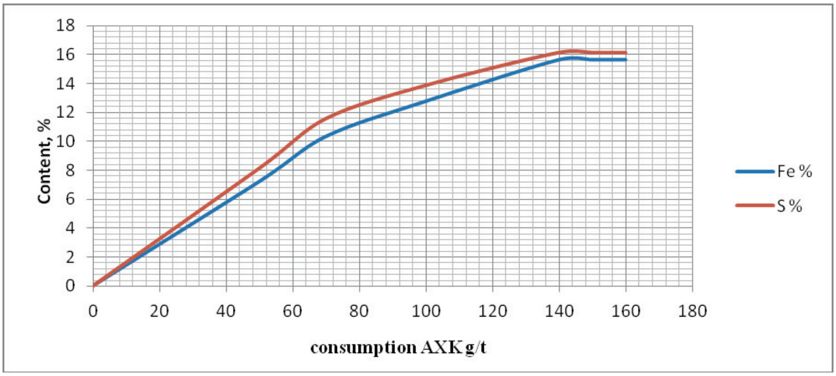


Fig. 9. Fe, S content in the concentrate according to different collector intake (potassium amylxanthate)

The increase in the iron-sulfur content as a function of the collector would result from the increase in the rate of covering of the mineral surface by the collector (Fig. 9).

To determine the influence of the collector on the content of the pyrite. The quantities of chemical reagents were kept constant: H_2SO_4: 1000 g/t, and pine oil: 10 g/t, they were used at a dose of 50 to 150 g/t, the optimum quantity was reached at 140 g/t For levels of 16% Fe and 16% S.

It is also possible to remove the heavy metals, in particular zinc (ZnS), which has a content of 1.38% by floating the blende by adding the copper sulphate as a zinc activator. By excluding the supply of water to sulphide tailings, the production of AMD can be reduced or even eliminated. For this purpose, low permeability barriers must be provided, which prevent the infiltration of surface and underground water. These barriers can be made of soils with low hydraulic conductivities or low permeability synthetic materials (geomembrane or bentonitic geocomposite). According to (Dobchuk, 2013) The finer particle size and higher air inlet pressure values of the roofing materials helped maintain saturation, and a cover with capillary breakage (fine to coarse) reduced the flow of water. oxygen to less than 5% of the fluxes obtained on the uncovered residues. The built-in blanket (coarse to fine) reduces oxygen infiltration by at most 50% and as low as <1% of uncovered residues, Recoveries to reduce the infiltration into the accumulation areas of AMD-producing mining waste are similar to those developed for domestic, hazardous or nuclear waste landfills.

(Pabst et al. 2014) evaluate the hydrogeological and geochemical behavior of roofing system residues under controlled conditions. His results indicate that, for the imposed conditions, monolayer coatings become substantially desaturated, which sufficiently limits the flow of oxygen diffusion. As a result, these blankets do not effectively prevent the oxidation of sulphides in the tailings. (El Mkadmi et al. 2014) show the main results of a numerical study that aims to analyze the hydro-geotechnical response of the embankment in a narrow vertical construction site and the simulations illustrate how the constraints are influenced by the geometry of the site, the drainage and the filling sequence

5. CONCLUSION

Sulphide mining waste from the treatment of Pb, Zn, Cu and Ag ores by flotation poses a major problem for industrial players, particularly mining companies. The study concerns the development of sulphide mining wastes from the Chaabet-El-Hamra mine located in the north-east of Algeria. The conclusions drawn from this research are:

- Mining wastes resulting from the sphalerite flotation treatment are mainly composed of pyrite, marcasite, dolomite containing considerable inclusions of sphalerite (ZnS), the galena is practically absent in these discharges.

- In order to counteract the problem of acid mine drainage, flotation environmental desulphurization tests are carried out on several representative samples to separate the sulfur-rich fraction from the fraction low in sulfur.
- The results obtained by flotation are very significant in recovery and in sulfur content.
- The flotation rejects are again separated to recover the sphalerite containing heavy metals of zinc.
- The final waste containing sulfur-poor sulfur and dolomite may be recovered from sulfur-rich mining waste (monolayer recovery in the case of a semi-arid region of Algeria).

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