Activation of Dolomite for Passive Treatment of Mine Drainage in a Circular Economy Perspective with Zero-Waste Objective

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Abstract— Contaminated mine drainage results from the interaction between the running water and the components of a mine site. The treatment of mine drainage is mandatory, with respect to its long-term environmental impacts. For the case of closed mines, passive treatment of mine waters is generally the viable option. Passive treatment involves chemical, physical, and biological processes found in the environment, which is cost-effective and require little maintenance. Dolomite ($CaMg(CO_3)_2$) is often employed for passive mine water treatment. Dolomite dissolves and therefore neutralizes and reduces acidity, increases alkalinity; dolomite also remove metals, non-metals, and metalloids in contaminated mine waters. Moreover, its activation by half-charring enhances its performance for mine water treatment. Compared to raw dolomite, half-charred dolomite ($CaCO_3 \cdot MgO$) is more soluble (due to change in chemical composition), has a larger specific surface area (0.7 versus 23.0 m^2/g) and higher paste pH (7.9 versus 11.6), which contribute to enhance its performance in mine drainage treatment. In this study, half-charred dolomite will be prepared and evaluated for the treatment of mine drainage, sampled on the previously restored mining site of Normétal, Quebec, Canada. Dolomite will be characterised by X-ray diffraction, elemental chemistry (acid digestion followed by ICP-MS scan), and thermogravimetric analysis. Specific surface, pores volume and paste pH will be also investigated. Characterization will be performed before and after dolomite charring (temperatures 700 to 800°C, for one to six hours), with the aim to investigate chemical and mineralogical modification of dolomite through heating, as well as the origin of the improved performance of half-charred dolomite for the mine water treatment. Thereafter, batch scale experiments will be performed in 2L bottles, filled with mixture of dolomite and half-charred dolomite in various ratios. Two representative temperatures will be considered (4°C and 20°C) for kinetics (to determine the hydraulic residence time) and isotherms study (to predict the lifespan of the treatment system). Pilot scale test will be performed in 1m³ container manufactured from recycled high-density polyethylene. The results will be therefore used for the design of the field scale treatment system. Dolomite regeneration for reuse will be evaluated, aiming a zero-waste process.

Index Terms— Mine drainage, passive treatment, dolomite, zero-waste, circular economy.

I. INTRODUCTION

Mine drainage is the result of water movement through the components of a mine site, e.g., the interaction between the run-off waters and the mine waste rocks and tailings [1], [2]. Mine drainage is generated by the oxidation of the sulfide minerals following their exposure to oxygen and water and can be acidic (acid mine drainage; AMD, pH < 6), circumneutral (contaminated neutral drainage; CND, 6 < pH < 9), basic (pH > 9), diluted, mineralized, or saline [2]. Variable concentration of several contaminants can be found in mine drainage, like metals in cationic form (Al^{3+}, Cd^{2+}, Co^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, Ni^{2+}, Mn^{2+}, Pb^{2+}, Zn^{2+}), metals in anionic form (CrO_4^{2-}, MoO_4^{2-}), and metalloids and non-metals in anionic form (SO_4^{2-}, SeO_4^{2-}, AsO_3^{3-}, AsO_4^{3-}, $Sb(OH)_6^-$) [3], [4]. Among all above mentioned types of mine drainage, the AMD is the heaviest contaminated and has the strongest environmental impact. The low pH of AMD promotes the dissolution of minerals to liberate metals and anions and the growth of acidophilic microorganisms which are known for catalyzing the production of acidic waters [5]. The environmental impacts of AMD were classified [6] into four categories: chemical (increasing acidity and metals in the environment), physical (turbidity and decrease of light penetration in water bodies, adsorption of metals onto sediments, substrate modification), biological (acute and chronic toxicity, diseases, and death of living organisms) and ecological (bioaccumulation within food chain, loss of food sources, habitat modification). Although generally less contaminated than the AMD, the CND become increasingly considered as an important environmental concern [2], [7]. The CND contains elevated concentrations of sulfate, metal cations, and metal/metalloid oxyanions [7]. Since chemical elements are not biodegradable, they accumulate and threaten the existence of plants, animals, and humans even at low concentrations [8]. Moreover, mine drainage has season impacted flow and charge and its environmental repercussions may persist hundreds to thousands of years after the mine closure (Frau et al., 2015). Therefore, the treatment of the contaminated mine drainage is necessary, as an integral part of the sustainable water resource management [5].

Over the last decades, several researchers have extensively reviewed the technologies available for the treatment of the

mine drainage. One classification divides these technologies into separation processes (adsorption and membrane processes), advanced oxidation processes, and biological treatment [5]. To the above-mentioned, electrochemical technologies, chemical precipitation, and physical methods (evaporation, crystallization, photoreduction) can be added [9]. However, for the active treatment of mine effluents (mine in operation) there are many available technologies, whereas for passive treatment (after mine closure) the options are rather limited. Passive treatment of the contaminated mine drainage involves chemical, physical and biological processes found in the environment. For instance, passive chemical AMD treatment use chemical processes occurring in nature (carbonates dissolution) to reduce the acidity, increase the pH and the alkalinity, and to precipitate metals. Among the main passive treatment technologies available for mine drainage there are limestone drains and channels, passive sulfate-reducing biofilters (PBSR), permeable reactive barriers, swamps, aerobic wetlands, compost (bio)reactors, filters containing neutralizing materials and (bio)adsorbers [9], [10]. Passive treatment set ups are preferred for their low cost of construction, operation, and maintenance, and can be implemented in remote regions, since the operational needs are limited [5], [10]. Moreover, active treatment is not usually considered as a viable option for the long-term rehabilitation of AMD/CND – generating sites [11].

Carbonate rocks are often employed for the passive treatment of AMD, in either oxic or anoxic systems (drains, BPSR, filters). In anoxic environment, oxidation of iron is prevented, avoiding massive precipitation and drain clogging [11]. To reduce the gypsum ($CaSO_4 \cdot 2H_2O$) coating, and therefore passivation of carbonate rock, dolomite ($CaMg(CO_3)_2$) can be used instead of calcite ($CaCO_3$), as magnesium sulfate ($MgSO_4$) is soluble. Although dolomite dissolves slower than calcite, it was demonstrated that dolomite can be used to neutralize a very acidic AMD [12]. Dolomite is a common and abundant mineral, formed either as a primary precipitate or as a hydrothermal metamorphic phase. The term dolomite is used both for the mineral dolomite $CaMg(CO_3)_2$ and for the dolomite rock, which consists mainly of the mineral dolomite [13]. Dolomite was found effective for the removal of Ag^+, AsO_4^{3-}, Ba^{2+}, Cd^{2+}, Co^{2+}, Cu^{2+}, Hg^{2+}, Mn^{2+}, Ni^{2+}, Pb^{2+}, Sn^{2+}, Sr^{2+}, Zn^{2+} from contaminated waters [8], [14], [15]. However, the removal capacity depended on the contaminant, dolomite performance being very good towards Cu^{2+} (225 mg/g), and Pb^{2+} (up to 212 mg/g), and good towards Cd^{2+} (up to 93 mg/g), Zn^{2+} (up to 51 mg/g) and Ni^{2+} (up to 20 mg/g) [8]. Within adsorption studies, in most cases, the best model fit isotherm was Langmuir (monolayer adsorption on a homogenous surface) while adsorption mechanism followed the pseudo-second-order model (chemical adsorption). Thermodynamic study showed that except for the AsO_4^{3-}, the adsorption of metallic ions by dolomite was spontaneous

(Gibbs' free energy negative) and for most of the ions it was exothermic [8]. Metals removal mechanisms by dolomite were ion exchange, surface precipitation, surface complexation and adsorption, while the dominant mechanism depended on the target ion. When several contaminants were present (as for the case of a mine drainage), the selectivity of the dolomite depended on the electronegativity, ionic radius, solubility, and hydrolysis constant of the metal ion [8].

Various materials: naturals, wastes or by-products, can be modified to enhance their efficiency in wastewater treatment [16]. However, limited research work has been done on modified dolomite [8].

Yet, as shown in Table 1, one simple and effective way to significantly increase dolomite performance in metal removal in water remediation is its half-charring. Within the half-charring process, magnesium carbonate ($MgCO_3$) component of the dolomite ($CaMg(CO_3)_2$) decomposes into magnesium oxide (MgO) and CO_2 at temperatures around 800°C, as shown below:

$$CaMg(CO_3)_2 \rightarrow CaCO_3 \cdot MgO + CO_2$$

This process, involving changes into the chemical and mineralogical composition of the dolomite, induces the increase of its specific surface, pores volume, paste pH and pH_{PZC}, as well as increase of the solubility and reactivity of the half-charred dolomite compared to the raw dolomite [14], [17]-[19]. Consequently, metals removal capacity of half-charred dolomite is increased (Table 1), as well as its reactivity in neutralizing the AMD.

Complete metal removal was reported acquired from highly polluted Zn-rich AMD by two-step passive remediation system [20]. The first step was limestone-based ($CaCO_3$) whereas the second consisted of caustic magnesia powder (MgO) dispersed in wood shavings matrix. In addition to neutralize the AMD, the MgO-step was able to reduce high concentrations of Zn (364 mg/L) and significant concentrations of Mn, Cd, Co, and Ni, below the required limits for drinking water. However, by mean of half-charred dolomite, AMD treatment could be eventually acquired in one step [20].

The control of the pH and the removal of heavy metals in mine drainage treatment by cost effective neutralization agents (widely employed as less expensive) result in sludge and spent materials requiring safe disposal [9]. Yet, nowadays, sustainable mine drainage treatment focus on the recovery of the resources: water, metals and materials employed for the treatment [9]. In addition, within the context of a growing demand for the supply of critical and strategical metals, mineral-processing waste and mine water / sludge become promising secondary sources of metals [21]. Therefore, sustainable mining practices are more and more considered in active mines, to contribute to the zero-waste production goal in mining activity. For instance, at a field scale, membrane processes allow water recovery while biogenic / chemical sulfide precipitation allows metals

recovery. At laboratory scale, several technologies were evaluated for metals recovery: adsorption by activated carbon, selective sequential precipitation, electrochemical processes [9]. However, the sludge production was investigated for 108 mine sites in operation in different countries and the waste amounts production was found in the range of 20 to 135 000 dry tons per year [22].

The environmental impact and the potential of valorization of metal-sludge waste generated by AMD neutralization in active treatment system were assessed [21]. Metal recovery was evaluated by using diluted (0.5M and 1M) HCl and H_2SO_4. It was found that for base metals, 0.5M H_2SO_4 allowed > 90% recovery of Zn (4% content in dry sludge), Cu and Co, whereas for rare earth elements and yttrium 1 M HCl allowed > 90% recovery. However, the method is not selective and generates an acidic liqueur bearing several metals, therefore requiring further separation (e.g., selective precipitation, solvent extraction) [21].

Table 1. Performance of raw versus calcined dolomite for metals treatment

Metal	Dolomite adsorption capacity (mg/g)	Calcined dolomite adsorption capacity (mg/g)	Experimental conditions	Reference
As (III)	n/a	1.85	Dolomite: synthetic effluent 2 mg/L, pH=5, solid: liquid (g/ml) ratio 0.1:100	[26]
As (V)	0.65	2.16	Half-charred dolomite: synthetic effluent 0.05-2 mg/L, pH=7.2, solid: liquid (g/ml) ratio 0.1:100	[17]
Cd (II)	0.33	0.50	synthetic effluent 5 mg/L, pH=8.5, solid: liquid (g/ml) ratio 1:100	[27]
Co (II)	2.84	n/a	synthetic effluent 10 mg/L, pH=5.5, solid: liquid (g/ml) ratio 0.1:100	[28]
Co (II)	n/a	160	synthetic effluent 0.0002-2.5 g/L, pH=6, solid: liquid (g/ml) ratio 0.4:100	[29]
Cr (VI)	0.73	1.56	synthetic effluent, solid: liquid (g/ml) ratio 10:100	[30]
Cu (II)	225.7	n/a	synthetic effluent 50 mg/L, pH=5, solid: liquid (g/ml) ratio 0.1:100	[31]
Cu (II)	n/a	1000	synthetic effluent 500 mg/L, pH=5.5, solid: liquid (g/ml) ratio 0.05:100	[32]
Fe (II)	0.46	n/a	synthetic effluent 5 mg/L, pH=8.5, solid: liquid (g/ml) ratio 1:100	[27]
Fe (II)	n/a	> 900	synthetic effluent, pH=8, solid: liquid (g/ml) ratio 0.05:100	[33]
Mn (II)	1	180	Dolomite: synthetic effluent 50-202 mg/L, pH=6.3, solid: liquid (g/ml) ratio 0.75:100 Half-charred dolomite: synthetic effluent 50-2700 mg/L, pH=6.3, solid: liquid (g/ml) ratio 0.75:100	[15]
Ni (II)	2.0	4.7	synthetic CND, pH=6, solid: liquid (g/ml) ratio 0.75:100	[18]
Zn (II)	1.7	12.2	synthetic CND, pH=6, solid: liquid (g/ml) ratio 0.75:100	[18]

Within this context, the objective of this study is to develop and evaluate a novel approach for passive mine water treatment by modular drains filled with a mixture of high purity dolomite and half-charred dolomite. The appropriate mixture ratio will be studied, as well as the particles size, up to laboratory pilot scale (1 m^3). The modules will be manufactured from recycled high-density polyethylene HDPE (e.g., from mine air duct). The treatment technology will be transferable at field scale, with design recommendation and estimation of the lifespan. Spent dolomite, as well as precipitated metals, will be recovered.

For the sampling of the mine effluents as well as for the pilot test design (e.g., flow and hydraulic residence time), Normétal site in Abitibi region of Québec, Canada, is considered in this study. Normétal mine was an underground mine in operation between 1937-1975, where 10 million tonnes of Cu and Zn sulfurous ore were extracted. The tailings issued from the mineral processing were stored in three impoundments adjacent to Normétal village and Desméloizes river (Fig. 1).

An initial restauration in the '80 consisted in sand cover and revegetation. However, acidic seepage into the environment was observed through the Desméloizes river. Therefore, in 2004, SNC-Lavalin was mandated to develop and perform a new restauration project, which included: clean-up of the spilled tailings, stabilisation of retention dams, prevention of the surface erosion, application of geomembrane to reduce the penetration of the oxygen and water into tailings, construction of toe drain and manhole network and construction of surface drainage network, revegetation of covered areas using residual fertilising materials. This work significantly improved water quality

(pH increased from 3.0 to 6.9, Fe concentration decreased from 298 to 3.6 mg/L and Zn concentration decreased from 6.9 to 0.12 mg/L), eliminate sediment transport, and stabilized the dams.

However, mine water could be occasionally in the AMD / CND category, with respect to regulatory requirements [23], [24].
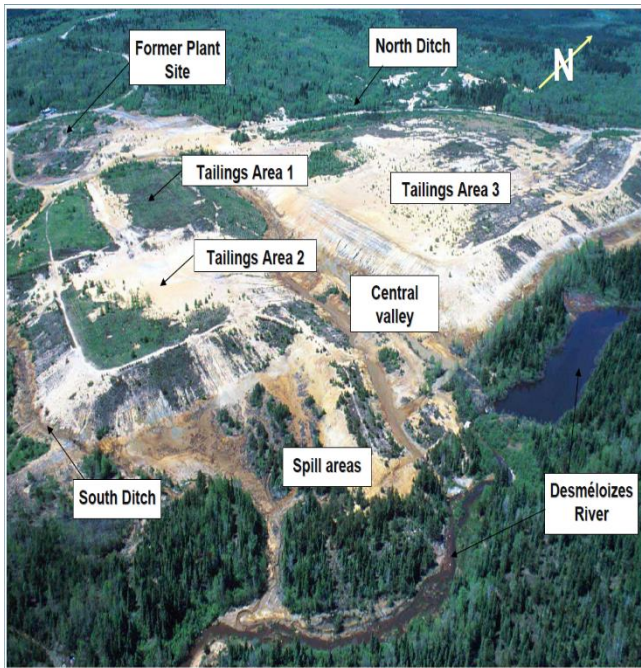

Figure 1. Normétal site before restauration [25]

II. MATERIALS AND METHODS

The dolomite employed in this study is supplied from quarry located in the Côte-Nord region of Québec, Canada. Characterization before and after dolomite half-charring, includes mineralogy by X-ray diffraction (XRD), elemental chemistry (acid digestion followed by ICP-MS scan), thermogravimetric analysis (TGA), specific surface and pores volume, paste pH and pH_{PZC} [18], [19]. The aim of the characterization is to investigate dolomite purity, chemical and mineralogical modification through heating, as well as the origin of the improved performance of the half-charred dolomite for the mine water treatment. Raw dolomite will be charred in an oven, under atmospheric conditions (air). Two steps were reported for the thermal decomposition of dolomite in air [17], [30], [34]-[36]:

$$CaMg(CO_3)_2 \rightarrow CaCO_3 \cdot MgO + CO_2$$

$$CaCO_3 \rightarrow CaO + CO_2$$
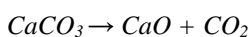
The first step of dolomite decomposition engenders a solid rigid product constituted of calcite ($CaCO_3$) and periclase (MgO). However, the mechanical strength of granular dolomite was reported decreasing gradually with heating from 106 N/grain (raw dolomite) to 44 N/grain (dolomite charred at 700°C), and 28 N/grain (dolomite charred at 800°C) [30], [36]. Heating above 800°C dramatically reduces dolomite's mechanical strength, leading even to the disintegration of grains, which is related to the decomposition of $CaCO_3$. The main structure-forming component is the Calcium carbonate ($CaCO_3$) which decomposes at temperatures starting with 800°C [36]. Therefore, to ensure the mechanical strength of half-charred dolomitic stones for mine water treatment in dolomitic drains (system with flow), dolomite will not be heated above 800°C in this study [37].

Analysis XRD and TGA showed that the first step of dolomite decomposition occurs between 600 to 800°C [35]. However, significant decomposition of $MgCO_3$ is acquired starting with 700°C.

Charring temperature and duration impact the surface area of the half-charred dolomite (Table 2).

Table 2. Surface area of half-charred dolomite according to charring temperature and duration

Charring temperature, °C	Charring time, hours	Surface area m²/g	Reference
700°C	1	2.83	[17]
	2	3.41	
	4	5.73	
	8	7.31	
700°C	5	2.6	[36]
750°C	1	4.2	[19]
750°C	1	2.91	[34]
	8	5.16	
800°C	1	5.6	[17]
	2	6.15	
	4	10.86	
	8	11.81	
800°C	6	19.5	[14]
	12	23.0	
800°C	1	4.44	[34]
	8	6.12	
800°C	12	11.3	[38]
800°C	5	2.4	[36]

However, for the same set of charring parameters: time and duration, different specific surfaces were reported (Table 2), for instance for charring 8h at 800°C, 6.12 m²/g [34] and 11.81 m²/g [17] were reported. Also, for dolomite charred 12h at 800°C, 11.3 m²/g [38] and 23.0 m²/g [14] were reported. Moreover, for dolomite charred one hour at 750°C, 2.91 m²/g [34] and 4.2 m²/g [19] were reported. Therefore, raw dolomite's purity and its initial granulometry also impact the surface area of the dolomite half-charred.

For the high purity dolomite employed in this study, charring will be done at temperatures within the interval 700 to 800°C, for durations of one to six hours. For economic reasons, higher temperature will be preferred to longer charring time. For raw dolomite with a specific surface of 0.89 m^2/g it was reported [17] that an increase of 100°C of charring temperature (from 700 to 800°C) doubled the specific surface of dolomite charred one hour (2.83 versus 5.6 m^2/g). Doubling the charring time (from one to two hours) at 800°C increased with only 10% the specific surface of half-charred dolomite (5.6 versus 6.15 m^2/g). However, four hours of charring at 800°C doubled the specific surface of half-charred dolomite compared to one hour (5.6 versus 10.86 m^2/g). In addition to the specific surface and pores volume, mechanical strength of charred dolomite stones will be also evaluated within this study, since micro texture, mineralogical composition, petrographic and microstructural characteristics affect mechanical, physical and engineering properties [39].

Compared to dolomite, for the case of the half-charred dolomite, significant increase of the paste pH and pH$_{PZC}$ was reported: 11.6 versus 7.9 and respectively 11.1 versus 9.6 [18]. This would directly contribute to the improvement of the AMD treatment, as raw dolomite fails to increase the pH of an AMD to 6,0 whereas calcite rises the pH of an AMD up to 6.5 in anoxic environment [11]. However, the MgO-DAS (dispersed alkaline substrate) final step of the multi-step alkaline treatment system evaluated by Macías et al., 2012, increased the pH of the AMD from 3.55-3.61 to 9.33-10.35.

On spent dolomite, characterization include elemental chemistry (complete acid digestion followed by ICP-MS scan) and thereafter mineralogy by X-ray diffraction (XRD), with the aim to identify and quantify the contaminants removed from the treated mine water, as well as their mineralogical form. However, challenges are expected, as the newly formed secondary minerals in post-treatment residues are often poorly crystalline or amorphous [40]. Regulated leaching tests TCLP (U.S. EPA Method 1311), SPLP (U.S. EPA Method 1312), as well as the MA.100 - Lix.com. 1.1 leaching protocol for inorganic species CTEU-9 and CTEU-10 [41] will be performed to assess the mobility of inorganic species (treated contaminants) under different condition (e.g. water, acid rain). Moreover, sequential extraction protocol [42], [43] will be applied. Sequential extraction involves dissolving chemical elements presents in a solid sample under the action of several reagents added successively to the same aliquot of solid. Thus, heavy metals are separated into different fractions according to 6 operational procedures, to extract: the water-soluble fraction, the exchangeable fraction, the acid-soluble fraction, the reductible fraction, the fraction named oxidizable and linked to the organic matter or to sulfides, and finally the residual fraction. The aim of leaching testing is to evaluate the conditions to recover metals from sludge and to formulate recommendations for appropriate waste management [20], [40], [44].

Characterization of the mine effluents include the following measures and analysis: pH, Eh, conductivity, dissolved oxygen, acidity / alkalinity, sulfate, elemental chemistry (ICP-MS scan) and iron speciation (Fe^{2+} / Fe^{3+}). Mine waters, sampled at the restored mining site of Normétal, are collected at six points identified as NO-3 to NO-8. Based on previous data, some of the mine effluents could be in the AMD category, whereas others in the CND category.

A. Batch Scale Experiments

Cylindrical 2L bottles with wide inlet will be employed for batch scale experiments. The bottles will be filled either with raw dolomite stones, or with mixture raw: half-charred dolomite stones in various ratios. The selected granulometry for batch scale experiments is 20 to 25 mm. Two representative temperatures (4°C and 20°C) will be considered for kinetics and isotherms study. Kinetics study aims to evaluate the optimum hydraulic residence time necessary for the treatment of the mine effluent. Also, it allows to evaluate the quality of the effluent for various contact time (e.g., 2h, 8h, 12h, 16h, 24h et 48h). Isotherm study aims to predict the lifespan of the treatment system. Therefore, for a constant quality of the mine effluent, testing will be performed for different solid: liquid ratio (e.g., 1: 10; 1: 20; 1: 50). Isotherm study data will be evaluated according to Langmuir and Freundlich models. As for kinetics study data, modeling will allow to drawn conclusions on metal removal mechanisms for main cations. The results will be therefore used for the design of the pilot scale treatment system with the final objective to obtain treated effluents complying with provincial [23] and federal [24] regulations.

B. Pilot Scale Experiments

Pilot scale test will be performed in 1m³ container manufactured from HDPE. The selected granulometry for the dolomite stones in pilot scale experiments is 25 to 40 mm. The effluent will move through a simulated mine drainage captation pond to aerate, oxidate Fe^{2+} into Fe^{3+}, and therefore increase Fe^{3+} removal (Fig. 2). The effluent will enter downflow into a first empty compartment, then it will circulate upflow to fill the dolomite compartment of the pilot (according to the principle of communicating vessels). The upflow allows to exploit the dolomite in its entire volume and avoid the formation of preferential flow channels. Several 1m³ units may be necessary to acquire the target quality for the mine effluent (Fig. 2). The results of pilot scale experiments will be thereafter used for the design of the field scale treatment system.

C. Dolomite and Metals Recovery

Studies on dolomite regeneration and reuse are scarce. The HCl was found as the most suitable for leaching metal cations at the dolomite surface [8]. However, the HCl solution of pH 2.9 allowed very low recovery of metals (Ni and Zn) on

half-charred dolomite surface, whereas HCl solution of pH 1.0 dissolved the half-charred dolomite [45]. Leaching tests TCLP, SPLP, CTEU-9 and CTEU-10 will provide valuable information for the disposal of spent dolomite whereas sequential extraction will provide information for metals recovery. Regeneration study and metal recovery will be conducted on the dolomite spent in the pilot system, as more representative for field treatment than batch tests. Segregation of contaminants is expected.
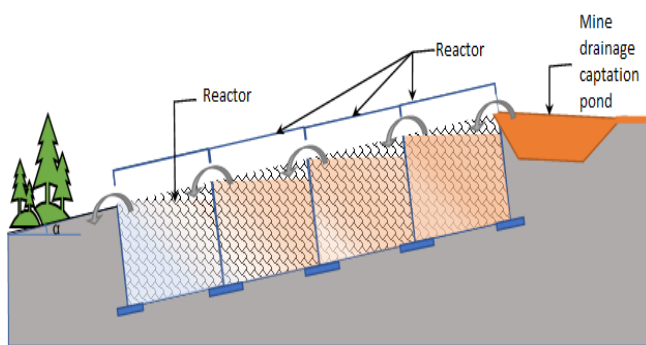

Figure 2. Schematic view of the dolomite passive treatment system

Visual observation was performed [40] during the dismantling of the column reactors of half-charred dolomite employed to treat mine effluents (AMD and CND). The formation of gypsum was reported at depths of 0-3 cm from the inlet, whereas Fe-(oxy) hydroxides were dominant from 3 cm to the bottom. Therefore, visual observation will be made during the dismantling of the pilot reactor employed in the present study, and the sampling of the spent dolomite will be performed with concerns of representativity. Our first hypothesis is that drying followed by mechanical abrasion will allow to separate the dolomite from the salts and oxides deposits. Thereafter, dolomite will be reused to refill a HDPE container while the residue will be subject to hydrometallurgical process to recover valuable minerals and metals. The second pathway is drying and grinding followed by separation of dolomite powder from impurities (e.g. metals). Thereafter, dolomite powder will be evaluated for using as fertiliser and / or neutralizer.

III. RESULTS EXPECTED AND DEPLOYMENT STRATEGY AT FIELD SCALE

Calcite ($CaCO_3$) is the most employed carbonate for the passive treatment of the mine drainage. Dolomite [$CaMg(CO_3)_2$], although less employed than calcite, can be effective for the neutralization of a very acidic AMD [12]. However, for the best of our knowledge, half-charred dolomite [$CaCO_3 \cdot MgO$] has not yet been used for the passive treatment of the mine drainage at laboratory pilot and / or field scale. However, an AMD (pH 3.55) highly polluted in Zn (364 mg/L) was successfully treated [20] by a two-step remediation system consisting of limestone ($CaCO_3$) and

caustic magnesia powder (MgO). Therefore, based on the existing literature, and on the data collected following laboratory pilot testing in this study, a treatment system will be designed for successfully field scale application. The dolomite passive treatment system (Fig. 2) for mine drainage (AMD / CND) will consist of the necessary number of HDPE modules filled with mixture of dolomite and half-charred dolomite to obtain treated effluents complying with provincial [23] and federal [24] regulations.

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