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Exploring the economic potential of an electrochemical alternative to managing acid mine tailings

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Abstract

Today, potentially acid generating tailings are concentrated, and the risk of oxidation is reduced by either covering them with water or with a capillary barrier. Any effluent seeping through the containment area over the coming few hundred years is treated using a number of different methods. However, none of these methods propose a means to treat potentially acid generating tailings as a “run-of-plant” stream.

In this work, we will venture to explore the economic potential of a “run-of-plant” electrochemical technology alternative that can both neutralise acid tailings effluent as well as contribute to concentrating the remaining heavy metal salts. This will be accomplished by conceptualizing the electrochemical process, defining a stochiometric model around it and tying the results to current commodity prices. The presentation will close with a discussion of the limitations of the model as well as possible impact on future mineral process operations.

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1. Introduction

Acid mine drainage (AMD) is, according to some, “…an environmental problem of global scale” (Moncur, 2006), while for others, AMD “…is the second biggest challenge after climate change” (Tuffnel, 2017).

However, the production of AMD is a natural phenomena of pyrite oxidation in the presence of water and oxygen (Simate & Ndlovu, 2021a) and it is associated with massive sulphide mining activity.

Today, massive sulphide mining activities manage potentially acid generating (PAG) tailings by concentrating them and reducing the probability of pyrite oxidation by either covering them with water or with a capillary barrier (Simate and Ndlovu, 2021b). Any effluent seeping from these containment areas over the coming few hundred years is treated using several different methods (Simate and Ndlovu, 2021c).

The most common of these methods uses neutralising minerals such as lime (CaO) to treat any effluent by increasing pH and precipitating out most, if not all, of the dissolved heavy metals (Taylor et al., 2005). On the other hand, several novel methods are being developed that aim to capture some residual value in the tailings (Simate and Ndlovu, 2021d).

However, none of these methods propose a means to treat potentially acid generating tailings as a "run-of-plant" stream thus eliminating the need for acid generating tailings storage facilities and associated costs and risks.

The aim of this work is to explore the economic potential of one such technology in the treatment of PAG tailings in a "run-of-plant" scenario. Specifically, the economic potential of an electrochemical approach will be evaluated and compared with the currently most common method of PAG tailings mitigation. This will be accomplished, following a brief review of electrochemical patent literature, by conceptualising a complete "run-of-plant" process around one such electrochemical mechanism, defining a stochiometric model around it, tying the results to current commodity prices followed by two case studies. The presentation will close with a discussion of the limitations of the model as well as possible impact on future mineral process operations.

2. Background

As illustrated in Fig. 1, Simate and Ndlovu (2021d) uses the 3Rs (Reuse, Recovery and Recycle) to categorise the different methods and technologies addressing AMD management.

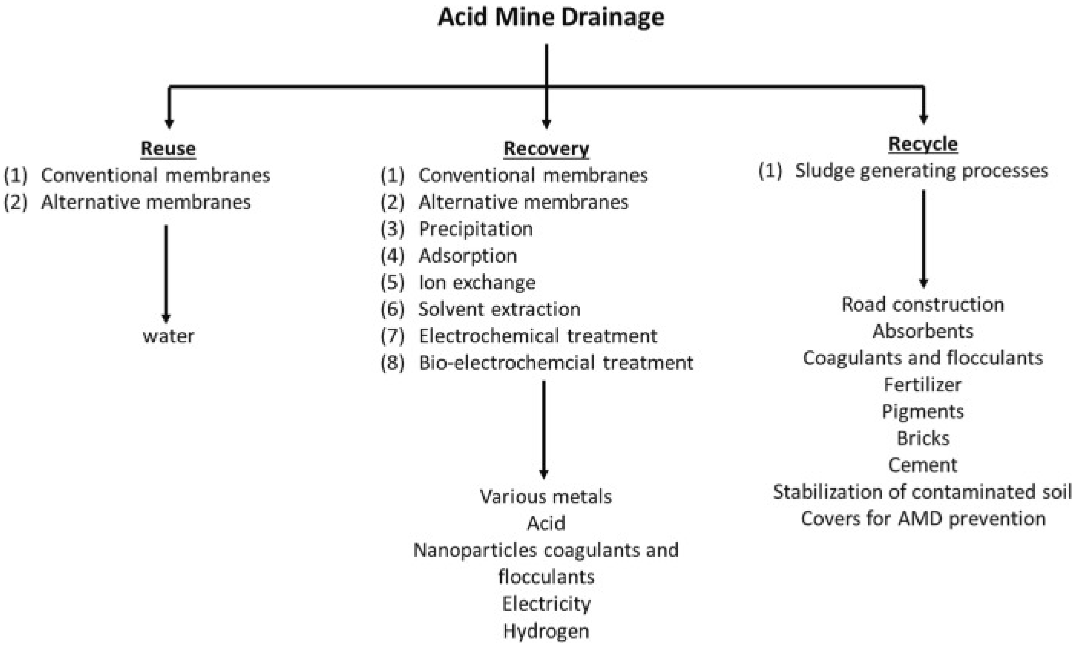


Fig. 1. 3Rs of AMD according to Simate and Ndlovu (2021d).

Of these methods and technologies, the description of electrochemical treatments is limited to electrocoagulation, electro-flotation and, electrodeposition (aka electrowinning) with the aim to not only increase AMD effluent pH but also to capture metals in different forms. The common characteristic is the application of electric energy (voltage and current) which is accompanied by the electrolysis of water producing hydrogen in the case of electrocoagulation and electro-flotation.

An example of electrochemical treatment technologies that use electricity to increase AMD pH to environmentally acceptable levels can be illustrated by the patent applications of Park et al. (2016) and that of Thompson-Brewster (2022).

2.1. Park et al. (2016)

A schematic of the Park et al. (2016) electrochemical cell is illustrated in Fig. 2 and described as follows:

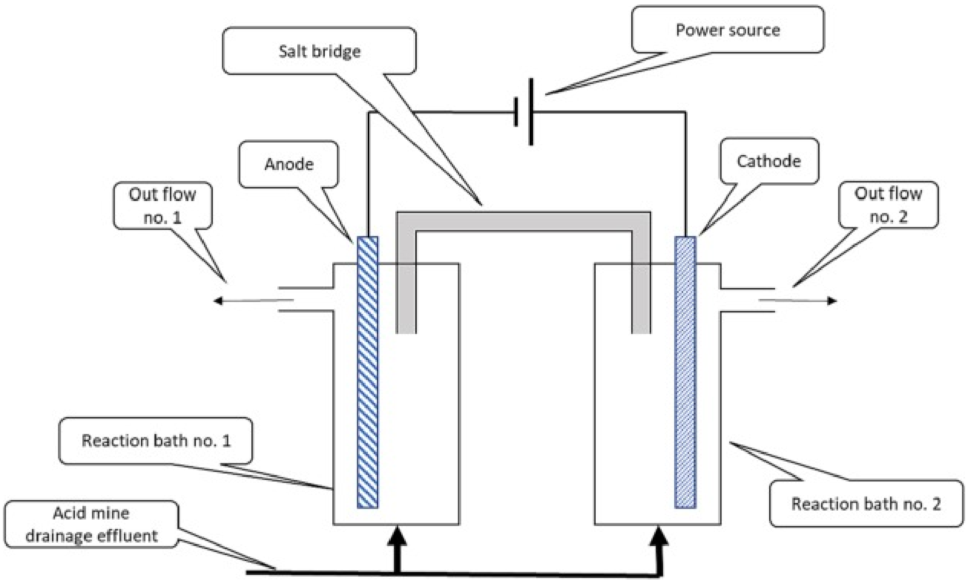


Fig. 2. The Park et al. electrochemical AMD treatment cell.

“The apparatus includes first and second reaction baths for receiving acid mine drainage, wherein the first and second reaction baths are provided with inlets and outlets and are separated from each other to prevent communication between acid mine drainages, an electrically connected anode and a cathode installed in each of the first and second reaction baths, and an electron transport medium for connecting the first reaction bath receiving the anode and the second reaction bath receiving the cathode. The electron transport medium blocks the transport of metal cations and allows the transport of electrons between acid mine drainages in the first and second reaction baths. Ferrous ions are oxidized to ferric ions in the acid mine drainage to precipitate hydroxides in the first reaction bath, and hydroxide ions are produced in the second reaction bath.”

The out flows for both reaction baths are processed in precipitation baths that capture the metal precipitates which are then filtered and sent for processing to extract the metals. It should be noted that Park et al. (2015) provides some energy consumption results for different anode compositions.

2.2. Thompson-Brewster (2022)

The cell proposed by Thompson-Brewster (2022) differs with the Park et al. (2016) cell in that the AMD effluent is fed only into reaction bath no. 2 while reaction bath no. 1 is filled with a 1 M sodium borate buffer. As with the Park et al. cell, the ultimate goal of this process is to precipitate out desired metals from the AMD solution as demonstrated in Thompson-Brewster et al. (2020).

However, not all AMD electrochemical treatment processes require an electrical energy input as illustrated by Stiller (1985).

2.3. Stiller (1985)

The Stiller (1985) process reduces to a simple galvanic reaction (Fig. 3). In the Stiller (1985) embodiment, the anode is composed of a material which is more electroactive than the cathode. “In a preferred embodiment iron is employed in the anode to serve as a sacrificial anode with respect to pyrite which is used in the cathode”.

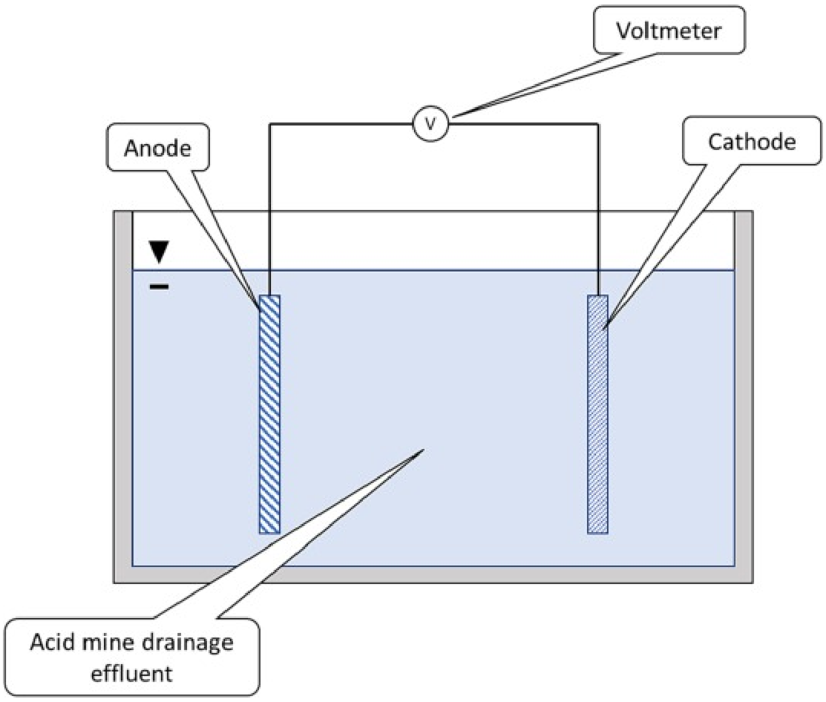


Fig. 3. Simple galvanic cell embodied in the Stiller patent (1985).

3. Defining a “run-of-plant” electrochemical PAG tailings treatment process

Most, if not all, PAG tailings treatment processes treat only the effluent leaking from PAG tailings storage facilities. Predicting the acid generating potential of different massive sulphide tailings storage facilities is typically determined through the use of acid-based accounting and column test work (Akesseh et al., 2014, Ouakibi et al., 2014, Jouini et al., 2020).

However, in a “run-of-plant” context, the PAG tailings are processed as they are produced. As a result, the approach to predicting the amount of sulphuric acid potentially produced and sizing the treatment process can be reduced to applying the following assumptions.

Assumption #1: the main constitute defining the acid generating potential of a massive sulphide mine is the pyrite (FeS_2) content of the ore.

Assumption #2: all pyrite is converted to sulphuric acid through oxidation as defined by the following equation:

$$FeS_2(s)+7\ O_2(g)+2\ H_2O(l)\rightarrow 2\ Fe^{2+}(aq)+4\ SO_4^{2-}(aq)+4H^{+}(aq) \quad (1)$$

Assumption #3: Estimating the economic potential of this process is only viable if applied to a “Run-of-Plant” PAG tailings stream.

Assumption #4: Technologies exist today that can process any PAG tailing into a dry stackable sterile tailing and a separate acid only stream.

With these assumptions, it is possible to define the electrochemical PAG tailings treatment process concept as illustrated in Fig. 4.

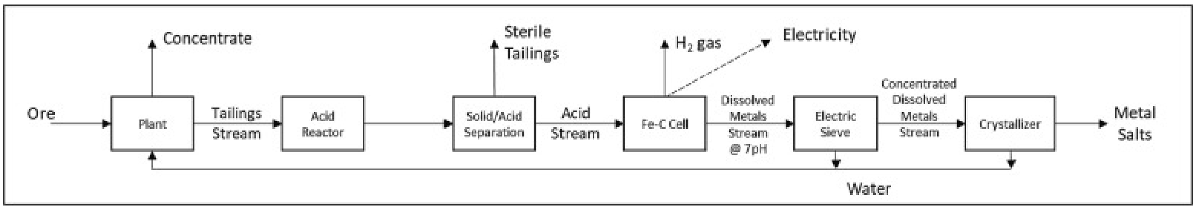


Fig. 4. The electrochemical PAG tailings treatment process concept.

Currently, a massive sulphide ore is processed in a plant or concentrator that produces a product concentrate and a potentially acid generating (PAG) tailings stream. However, it is proposed that the PAG stream feed an acid reactor.

There are at least two acid reactor technologies that are currently used to treat concentrate streams: Metso:Outotec's Biox™ process (Metso:Outotec, 2021) and Glencore's Albion™ process (Glencore Technology, 2022). In the Biox™ process, bulk concentrate is fed into a series of bioreactors where bacterial cultures oxidize the pyrite producing a solid/acid stream that is separated in a series of decantation thickeners. The resulting oxidized solids stream is sent to CIL leaching while the liquid acid waste stream is passed through a series of limestone neutralisation tanks followed by a thickener for water / sludge separation. In the Albion™ process, the bulk concentrate is reactivated in a stirred mill before being fed into the Albion™ leach process where acid and oxygen are added. The resulting product is then neutralised with limestone before being separating into solids and liquid streams.

In the proposed process illustrated in Fig. 4, the acid reactor can be either the Biox™ bioreactors or the Albion™ process leach. In either case, the product of the acid reactors would feed solid / acid separation equipment defined by decantation thickeners and filter presses. The output of this would be a sterile dry stackable solids tailings stream and a liquid acid stream.

The liquid acid stream would feed a series of electrochemical cells each having a consumable iron anode and a neutral carbon-based cathode as opposed to the ideal embodiment of an iron anode and a pyrite cathode in the Stiller patent (1985). These cells would produce hydrogen gas, electricity and a neutral ($6.0<pH<6.5$) liquid stream heavily laden with dissolved iron (and other heavy metals).

The metal concentration of this liquid stream is increased through an electric sieve leveraging similar mechanisms as found in an electrostatic air dehumidifier (Blum, 2008). Finally, a crystallizer is used to produce a metal salt that can potentially be used as a fertiliser (Koenig & Kuhns, 2010) or reprocessed to extract iron and other heavy metals (Yu et al., 2017).

3.1. Stoichiometric model

It is possible to estimate the amount of sulphuric acid produced in the acid reactor (Fig. 4) as a function of the pyrite content of a PAG tailing using the stoichiometry of Eq. (1).

Knowing that the electrochemical cell (Fig. 3) has an iron sacrificial anode and a neutral carbon cathode, it is possible to define the galvanic cell reaction as follows:

3.2. Galvanic cell reaction

$$Fe(s)+2H^{+} \rightarrow Fe^{2+} + H_2(g) \qquad (2)$$

Anode Reaction:

$$Fe(s) \rightarrow Fe^{2+} + 2e- \qquad 3)$$

Cathode Reaction:

$$2e- + 2H^{+} \rightarrow H_2(g) \qquad (4)$$

With the stoichiometry of Eqs. (2), 3), (4), it is possible to estimate the amount of hydrogen gas that will be produced in this cell as well as the resulting amount of iron sulphate salts from the subsequent concentration and crystallisation stages of the process.

Knowing that the cell potential is 0.44V for this electrode chemistry (Bagotsky, 2006) and that the charge carried by each electron is 1.6×10^{-19} Coulombs along with Avogadro's number, it is possible to use the reactions defined by Eqs. 3), (4) to estimate the amount of electrical energy produced by this electrochemical cell as a function of pyrite content of a given tailing.

The resulting amounts, as a function of pyrite content, are found in Fig. 5 while the associated trendline relationships are described by Eqs. (5), (6), (7), (8), (9).

Sulphuric acid (kg/mt ore): $m_{H2SO4}=1634.8\times\%$ pyrite (5)

Fe anode mass consumed (kg/mt ore): $m_{Fe}=931.02\times\%$ pyrite (6)

Hydrogen gas (kg/mt ore): $m_{H2}=33.343\times\%$ pyrite (7)

Fe sulfate (kg/mt ore): $m_{FeSO4}=3798.7\times\%$ pyrite (8)

Electric Energy (kWh/mt ore): $E_{elec}=821.02\times\%$ pyrite (9)

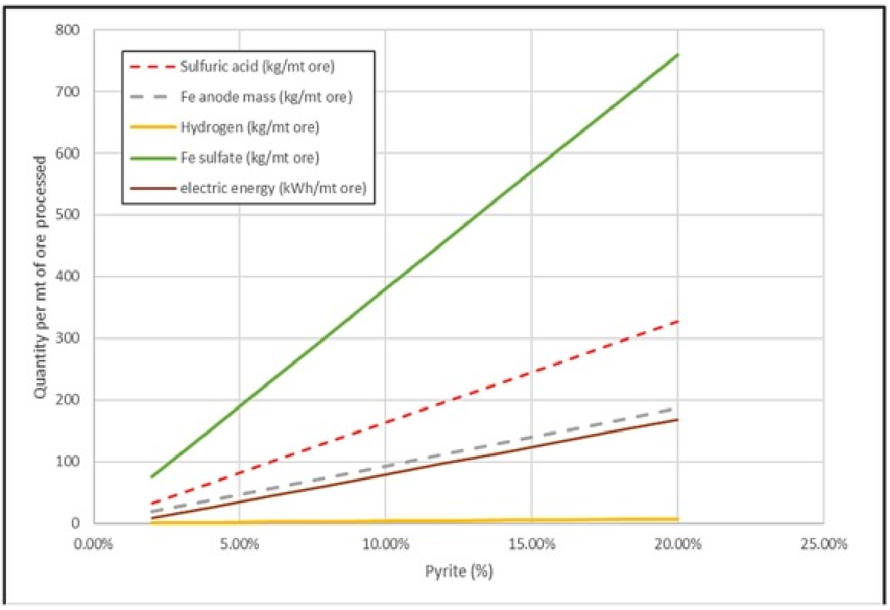


Fig. 5. Consumable (Fe anode) and produced quantities of an Fe-C electrochemical cell with sulphuric acid electrolyte as a function of pyrite content.

As a point of comparison, the amount of lime (CaO) required to neutralise the same amount of sulphuric acid is also determined and found in Fig. 6 along with the estimated amount of produced gypsum (CaSO4) while the associated trendline relationships as a function of pyrite content are found in Eqs. (10), (11) below.

CaO consumption (kg/mt ore) $m_{CaO}=935.27\times\%$ pyrite (10)

CaSO4 production (kg/mt ore): $m_{CaSO4}=2270\times\%$ pyrite (11)

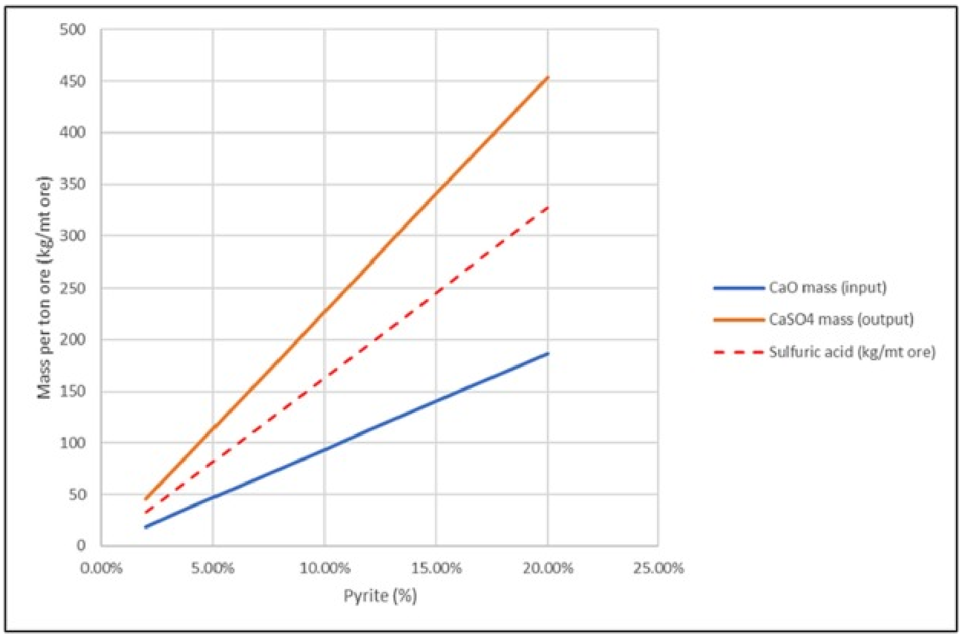


Fig. 6. CaO consumption and CaSO4 production as a function of pyrite content.

Sulphuric acid production as a function of pyrite content is the same as that illustrated in Fig. 3 and defined by Eq. (5).

3.3. Economic benefit potential

Limiting the analysis to the electrochemical cell, the costs and price for the materials consumed and produced are found in Table 1 along with some price variations. The resulting values as a function of pyrite content is found in Fig. 7 You can also find the cost and value related to lime neutralisation as a point of comparison.

Table 1. Quantity values.

Item	**Price ($USD/unit)**	**Units**	**Reference**
CaO (lime)	110	mt	average price (Made-in-China, 2022a)
$CaSO_4$ $-2H_20$ (gypsum)	37	mt	average price (Statistica, 2021)
Iron anode (iron powder)	100	mt	price (India Mart, 2022)
Iron anode (worn consumable)	0	mt	consumables have already been paid for
Electricity	0.10	kWh	average price USA (Energybot, 2022)
Hydrogen (green)	5.76	kg	average price USA (Clean Energy Wire, 2022)
$FeSO_4$	75	mt	average price (Made-in-China, 2022b)

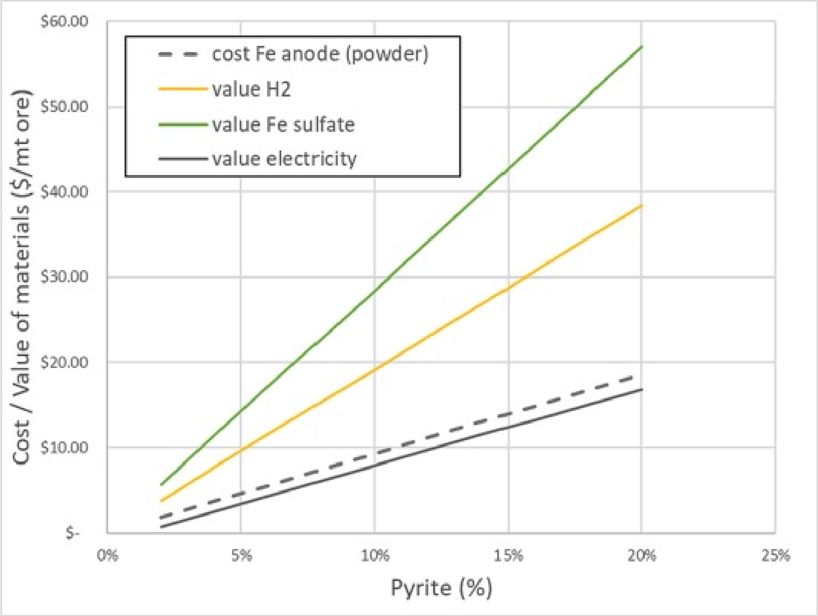


Fig. 7. Cost of Fe anode and value of produced quantities of an Fe-C electrochemical cell with sulphuric acid electrolyte as a function of pyrite content.

Fig. 8 illustrates the net benefit of four operating scenarios. Net benefit ($/mt ore) is calculated using the following equation:

$$\text{Net benefit} = \text{value of } H_2 + \text{value of } FeSO_4 - \text{cost of Fe anode} \quad (12)$$

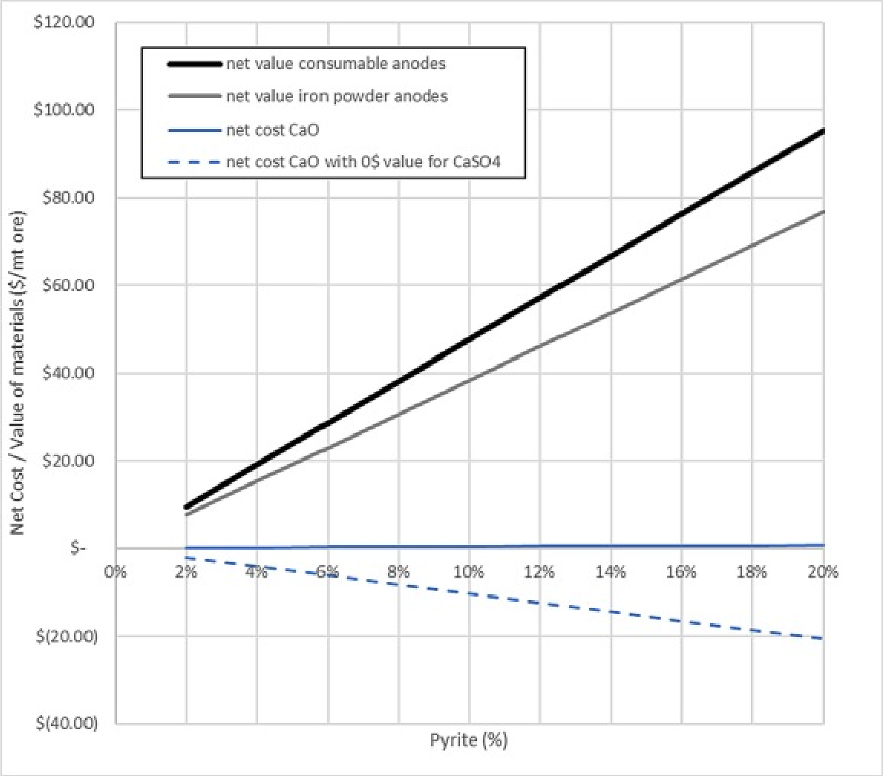


Fig. 8. Net benefit of the Fe-C cell vs Lime neutralisation.

It is important to note that in order to maximise the rate at which electrochemical neutralisation is achieved, the path between electrodes is assumed to be a short circuit. Consequently, it is not possible to use theelectricity value in the net benefit calculation.

The first scenario is lime (CaO) neutralization of the acid generated by the acid reactor (see Fig. 8) with no value given to the resulting sludge. In this case, the sludge is sent to a tailing storage facility. The net benefit related to this operating scenario is negative.

However, in the second scenario using lime (CaO) neutralization, the sludge, which is gypsum ($CaSO_4$-$2H_2O$), is captured, packaged, and sold at market value as illustrated by the SAVMIN process developed by Mintek (Simate and Ndlovu, 2021c). With the prices found in Table 1, this operating case, as a function of pyrite content, is essentially cost neutral with the value of gypsum almost equaling the cost of lime.

The third and fourth scenarios illustrate the net benefit developed by using the Fe-C electrochemical cell process as illustrated in Fig. 8. The difference is that in the third scenario, the anode is made of iron powder which has a cost. However, due to the high surface area that it presents, the rate of neutralizing the acid would be much greater than in the fourth scenario.

On the other hand, the fourth scenario would use any iron/steel discarded consumables (grind media scats, worn metal mill liners, worn AR plate from polymetallic mill liners, …) as anode material reducing the cost of the anode to $0.

3.4. Case studies

The following two case studies illustrate how the economic benefit potential model can be used to estimate the impact of using this electrochemical process for treating PAG tailings. The first of these two cases concern a greenfield application where the Fe-C electrochemical cell is used as a means to neutralise sulphuric acid in a “run-of-plant” process. The second case is a legacy PAG tailings site where the tailings have been identified as having economic potential for reprocessing.

3.5. New Prosperity case

Located in the west Cariboo region of British Columbia, Canada, the New Prosperity project was designed and planned by Taseko Mines Ltd. The project was not approved by the Canadian government “…for its impacts on Fish Lake, an area considered sacred by the Tsilhqot’in” (Lavoie, 2019).

It should be noted that the New Prosperity project is a gold-copper porphyry deposit which was to be mined over a period of 25 years extracting some 2.4 million mt Cu and 377000 kg Au (Taseko, 2022), the value of which is over $40 billion. This value is to be captured through the development of an open-pit mine located downstream of Fish Lake (aka Tezˆtan Biny) which was to feed a concentrator plant just north of lake as illustrated in Fig. 9. PAG tailings were to be stored underwater in a tailings facility some 2 km upstream of Fish Lake. It is important to note that tailings facility was to store 240 million metric tons of PAG tailings (Taseko, 2011) with an estimated pyrite content of 5%.

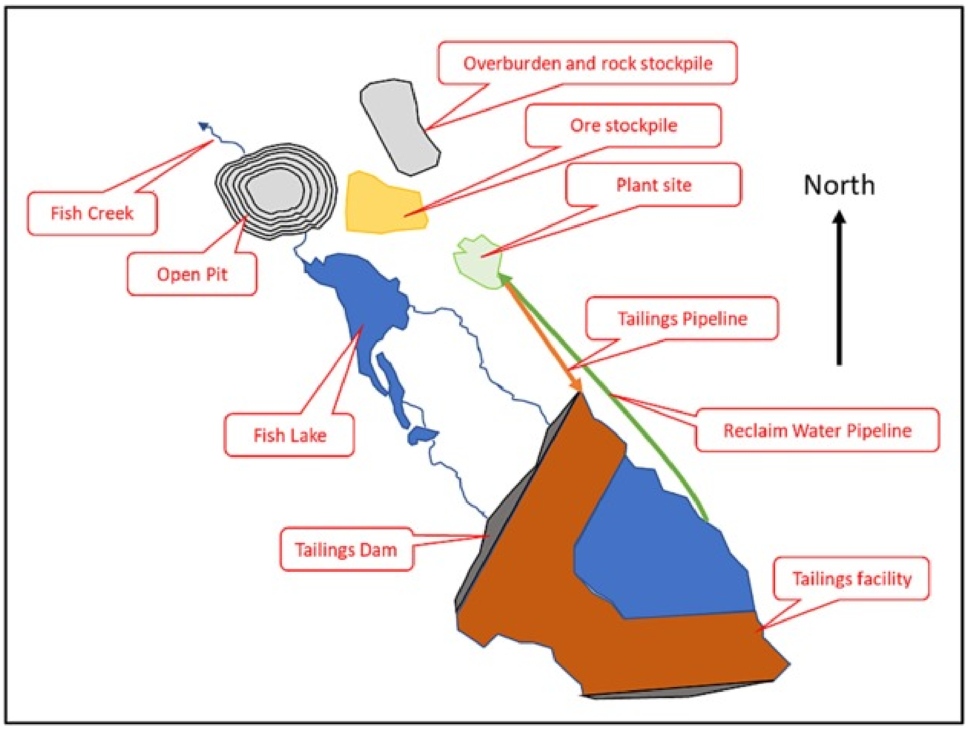
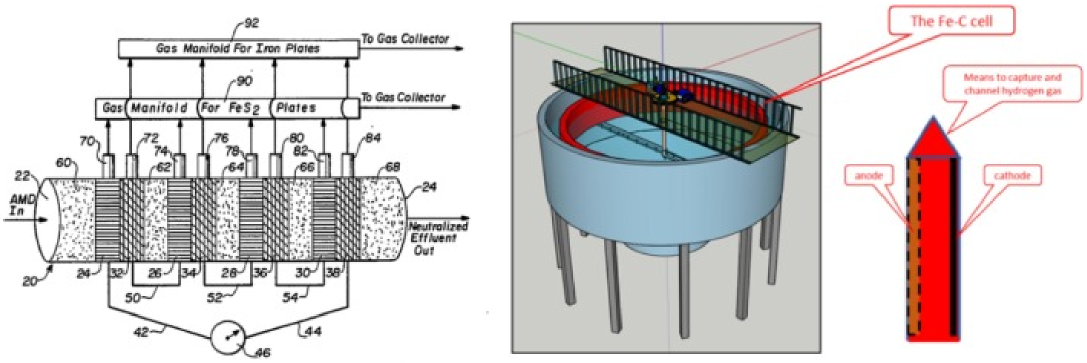


Fig. 9. Approximate layout of the New Prosperity mine and tailings facilities.



a) The Stiller vessel (Stiller, 1985)

b) A modified thickener with multiple Fe-C cells

Fig. 10. Alternative embodiments for the Fe-C cell.

For the New Prosperity site, Table 2 provides the results, over the life of the mine, for the potential benefits of four “run-of-plant” PAG tailings treatment scenarios leveraging the relationships defined by Eqs. (5), (6), (7), (8), (9), (10), (11) and the commodity prices found in Table 1.

Table 2. Potential benefits of a “run-of-plant” PAG tailings treatment.

Scenario	Description	Net Benefit
1	Lime treatment with sludge disposal	($1.2 billion USD)
2	Lime treatment with gypsum capture	$39.7 million USD
3	Fe-C cell with iron powder anodes	$4.6 billion USD
4	Fe-C cell with worn consumables as anodes	$5.7 billion USD

Based on these results, the use of lime (scenario #1) to neutralise the "run-of-plant" acid is a drain on the overall value of the New Prosperity project. Assuming the gypsum produced can be captured and marketed (scenario #2), the value of the gypsum has the potential to cover the cost of the lime used and thus maintain the overall value of the project.

On the other hand, using an iron powder anode (scenario #3) or spent iron/steel consumables (scenario #4), the "run-of-plant" electrochemical process described in Fig. 4 has the potential to add up to 14% more value to the project.

3.6. Zeehan tailings case

The Zeehan site is located in the township of Zeehan, Tasmania (Parbhakar-Fox et al., 2019). It is estimated that the site contains some 47,000 mt of tailings which were sampled and evaluated for geochemical properties (Bhowany et al., 2022). The results of the evaluation indicated that reprocessing of the tailings could potentially capture over $7 million USD in metal value. Furthermore, tailings were found to have a pyrite content varying from a low of 8% to a high of 56% with an average of about 38%.

For the Zeehan site, the use of Eqs. (5), (6), (7), (8), (9), (10), (11) along with the commodity prices found in Table 1, it was possible to estimate that the electrochemical process illustrated in Fig. 4 would generate about $145 per metric ton of tailings. Multiplied by the estimated mass of tailings, the electrochemical process could potentially add another $6.9 million, thereby doubling the overall value of the tailings.

4. Discussion

In summary, the Stiller cell with an iron anode and neutral cathode integrated into the "run-of-plant" circuit of Fig. 4, produces electricity which is used within the process, hydrogen which can be captured and various metal salts that also can be captured and subsequently processed. It also produces a sterile tailing that can be dry stacked or potentially used in applications such as paste backfill without the need for subsequent treatment. Consequently, this process falls under the 3Rs "Reuse, Recovery and Recycle" dimensions illustrated in Fig. 1.

Furthermore, the analysis demonstrates that the use of the Stiller cell in an AMD treatment process has the potential to add significant value to either a massive sulphide mine or legacy acid generating tailing pond reprocessing effort.

On the other hand, the Stiller cell is not the only electrochemical process being developed to treat AMD. Completing a US Patent Office search using the terms "acid mine drainage", "electrochemical" and "treatment" identified some 600 patents granted since 1956. A closer examination found 60 of these were the most relevant such as the contributions from Stiller, 1985, Park et al., 2016, Thompson-Brewster, 2022. Furthermore, of these 60 patents, 90% of them were filed since 1992 underlining the interest in the potential use of electrochemical mechanisms in the management of AMD related challenges.

In comparing all these other electrochemical AMD treatment technologies with the Stiller development, one observation can be made: they all leverage sulphuric acid as an electrolyte. Consequently, in a "run-of-plant" context, it should be possible to use the estimate of the amount of sulphuric acid produced in a "run-of-plant" context based on the assumptions #1 to #2.

Knowing the amount of sulphuric acid produced in a "run-of-plant" context per metric ton of ore as a function of pyrite content, it should then be possible to estimate the amount of value added of any electrochemical AMD treatment process provided that the stoichiometry of the underlying reactions can be determined.

However, these two assumptions along with the subsequent assumptions (#3 and #4) used in the analysis of the Stiller based electrochemical process also raise a few issues. The first issue is related to the limitations of the model used, followed by the challenges associated with industrial implementation and finally the potential impact of a possible successful industrial implementation of the Stiller based electrochemical process on mineral processing in the future.

4.1. Limitations

The development of this stoichiometric model is based on the assumptions that the main constituent defining the acid generating potential of a massive sulphide mine is the pyrite content of the ore (or tailing) and that all pyrite is converted to sulphuric acid through oxidation as defined by Eq. (1). However, this is only a partial description of the pyrite oxidation reactions that are associated with acid mine drainage. One needs to consider the impact of the two following reactions that can be present.

First, Fe^{2+} can be further oxidized:

$$4\ Fe^{2+}(aq)+O_2(g)+4H^+(aq)\rightarrow 4\ Fe^{3+}(aq)+2\ H_2O(l) \tag{13}$$

Then, the ferric cations (Fe^{3+}) can oxidize additional pyrite increasing the acidity of the solution:

$$FeS_2(s)+14\ Fe^{3+}(aq)+8\ H_2O(l)\rightarrow 15\ Fe^{2+}(aq)+2\ SO_4^{2-}(aq)+16H^+(aq) \tag{14}$$

As a result, the oxidation of pyrite may actually generate a significant amount of added acidity in the tailings stream.

On the other hand, the possible presence of neutralising minerals in an ore can have the opposite effect and reduce the resulting acidity.

Finally, it is important to underline that pyrite is not the only sulphide constituent present in an ore and these other sulphide minerals can potentially also contribute to increasing the acidity of a PAG tailings stream.

Therefore, the use of Eq. (1) to estimate the amount of sulphuric acid produced in a “run-of-plant” process could be considered a conservative.

4.2. Challenges

The main challenge to industrial implementation related to the Stiller based electrochemical process described in Fig. 4 will be related to scale-up to a “run-of-plant” application. Table 3 breaks down the scale-up challenge for each of the main components of this process.

Table 3. Scale-up challenges and mitigating means.

Component	**Challenge**	**Mitigating Means**
Acid reactor	Expand the use of the Biox™ and Albion™ processes to PAG tailings stream at “run-of-mine” flow rates.	Treat a portion of the “run-of-plant” PAG stream while sending the remainder to a “buffer” tailings area for the temporary storage. The PAG tailings in the temporary storage area will be emptied out and treated following the closing of the mine.
Solid/acid separation	As this equipment already treats “run-of-plant” tailings streams, acid resistant materials will need to be used to upgrade their use.	n/a
Fe-C cell	Scale the Stiller vessel (Fig. 10a) to treat the voluminous acid flow from the solid/acid separation process.	Examine alternate embodiments of the Stiller vessel such as adapting thickeners and decanters to include multiple Fe-C cells (Fig. 10b).
Electric sieve	Explore and complete the development of the electric sieve technology (TRL4→TRL9)	The electric sieve is a means to reduce the energy required to produce metal salts in a crystalliser. Consequently, the process will work without the electric sieve.
Crystallizer	Estimating the amount of energy required to crystallize the metal salts.	Solar energy used to crystallize the metal salts similar to what is used in lithium mining. Alternately, use the hydrogen captured to power the crystallizer.

4.3. Potential impact

Whether it be Stiller, Thompson-Brewster, or Park, the successful development and implementation of an electrochemical process to manage PAG tailings will also have a number of subsequent benefits as outlined below:

Lime - Currently, lime and its variants is used in the process to increase slurry pH. However, in order to increase the benefit of the electrochemical PAG tailings solution, lime use will be reduced and potentially eliminated in future mineral processing. Consequently, mineral processing will proceed with increased slurry acidity which will require other means to reduce equipment corrosion.

Comminution - As slurry pH decreases in order to increase the electrochemical PAG tailings solution benefits, greenfield projects will probably adopt dry comminution processes. This will reduce corrosion issues in comminution equipment. As it is expected that the electrochemical PAG tailings solution will leach out all remaining mineral value from an ore, the final grind size of the comminution circuit will probably increase without loss of overall recovery. Consequently, this will reduce the amount of energy required for comminution. This increase in grinding size will produce a coarser tailings which will in turn reduce the energy required for thickening and filtration.

Flotation - Flotation processes will be modified to include a slurry mixing and conditioning stage and will probably have to handle lower pH slurries.

Water - The electrochemical PAG tailings solution requires water. However, the amount of water needed is expected to be less than that required of typical flotation processes. Consequently, it is expected that research will explore different avenues to develop dry separation processes to replace flotation processes reducing the amount of water needed overall.

Iron - The electrochemical PAG tailings solution captures not only the dissolved iron from anode consumption but also the dissolved iron from the oxidised pyrite. Subsequent processing would contribute to overall iron production.

Legacy - Legacy tailings sites do not all have the metals value potential of the Zeehan site. However, adding the potential value that an electrochemical process could render would increase the number of legacy sites with economically extractable resources.

Social license - By capturing all of the value of a massive sulphide ore and leaving behind no toxic waste, it is possible that a project such as “New Prosperity” might one day find the social license to operate in an environmentally and culturally sensitive area.

5. Conclusion

The objective of this paper was to explore, in a “run-of-plant” context, the economic potential of an alternative electrochemical approach to managing PAG tailings. In meeting this objective, the following observations were made:

Technologies exist today that can leach all massive sulphides out of a “run-of-plant” tailings stream and separate that stream into a sterile solids stream and a metals laden acid stream,

Limiting acid tailings treatment to lime to neutralise the acid stream is cost intensive,

Capturing, for reuse, sludge generated by lime neutralisation can potentially offset the cost of lime consumption,

Using an electrochemical cell based process to treat the acid stream has the potential to generate a significant value to a massive sulphide mining operation,

Additional value can be generated by using worn steel liners and grinding media as anode material in the electrochemical cell.

These observations were confirmed through two case studies that highlighted the increased value of the ore body or legacy tailings.

In terms of implementation, the Stiller electrochemical cell can be potentially integrated into current thickener or clarifier designs.

If successfully demonstrated, the use of the electrochemical AMD processes would most likely motivate the use of dry comminution technologies as well as the development of dry separation technologies.

And finally, with the possible processing of mine tailings in a “run-of-plant” manner, it is possible to envision the elimination of PAG tailings storage facilities and the possible social acceptability of massive sulphide mining activities in environmentally and culturally sensitive areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Special issue articles Recommended articles

Data availability

All data used is found in the paper and cited in the references.

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