THE AMBS FLOTATION PROCESS FOR COPPER AND COPPER-GOLD ORES: BENCH TO PLANT APPLICATIONS

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ABSTRACT

The Air-Metabisulfite (AMBS) process has been developed to treat complex copper, molybdenum and precious metals (gold, silver) bearing ores using brackish and sea water. This process was able to produce significantly better copper concentrate grades and higher recovery than possible using conventional lime and/or cyanide based processes for certain complex ores with high sulphide gangue minerals. The AMBS technology in now used commercially following a rigorous evaluation process emanating from laboratory curiosity to plant applications. In addition, many projects have embraced this technology at a feasibility level involving various complex ore bodies.

This paper presents a summary of the findings from testing the AMBS technology on various ores types. Experiences gained from this successful development from bench to piloting and then to plant applications are also presented in this paper.

KEYWORDS

AMBS Process, Flotation of Copper, Molybdenum, Precious Metal (Gold, Silver) Ores, Sea Water Processing, Technology and Innovation, Process Plant Application

INTRODUCTION

Processing of sulphide copper, molybdenum and precious metal ores typically involves flotation of copper bearing minerals while depressing non-sulphide and other non-copper sulphide minerals such as pyrite, pyrrhotite and sometimes arsenopyrite. Though in many precious metal ores, the values are in these sulphide minerals as well. The conventional method employed in the industry to produce a saleable copper concentrate requires depression of these non-copper sulphide minerals using an alkaline pH above 9.5, though 10.5 to 11.5 is more common. Alkalinity is controlled by the addition of a pH modifier. Lime is normally employed as a pH modifier due to its relatively low cost; however, the costs associated with adding lime can be significant and the effectiveness of lime as a depressant could be drastically reduced when the process water supplied to the flotation circuit contains high level of dissolved salts. In some cases, a small amount of cyanide is used along with lime to depress non-copper sulphide minerals especially when its proportion to copper sulphide minerals in the ore is higher than three.

As ore bodies are becoming more complex, use of lime or cyanide based non-copper sulphide mineral depression methods are not effective in situations where there is a significant amount of clay minerals in the ore or where pyrite gets activated due to the presence of high amounts of copper, magnesium or other ions in solutions. The need for using raw sea water, brackish or poor quality municipal waste water, due to lack of fresh water availability or the desire to avoid using limited fresh water available for community purposes, is becoming essential to obtain the "license to operate". The challenge, however, is that the conventional copper flotation schemes are sometimes ineffective with these challenging water sources. This could be mainly attributed to pH buffering issues and precipitation of certain undesirable ions in solutions.

The need for an alternative to lime or cyanide based pyrite depressant is critical for selective flotation of copper from these complex ore bodies using problematic non-conventional water sources. This paper presents a solution that was advanced through rigorous development work carried out on various ore types followed by extensive proof-of-concept validation using bench and piloting program, which has now allowed two commercial applications. The technology that emanated from this work is known as Air-Metabisulfite technology (AMBS), the main subject of this paper (Gorain, 2009).

Challenges with the Reko Diq Project

The development of the AMBS project stems from addressing the challenges that were encountered for the Reko Diq project located in in the Chagai Hills district of Balochistan in south-west Pakistan. A major test program was carried out during the pre-feasibility study with an aim to replace the cyanide and lime based scheme due to concerns with the use of cyanide onsite in an environmentally sensitive location.

The Reko Diq deposit is a large low grade copper porphyry, with total mineral resources of 5.9 billion tonnes of ore with an average copper grade of 0.41% and gold grade of 0.22 g/tonne. From this, the economically mineable portion of the deposit has been estimated at 2.2 billion tonnes, with an average copper grade of 0.53% and gold grade of 0.30 g/ton, with an annual production estimated at 200,000 tonnes of copper and 250,000 ounces of gold contained in 600,000 tonnes of concentrate. The Reko Diq project is managed by Tethyan Copper Company, a 50:50 joint venture of Barrick and Antofagasta Minerals (AMSA).

The flotation work initiated by Tethyan during 2007 using conventional process showed that the site water had a detrimental effect on flotation performance. The head assays and the locked cycle results from the conventional flotation process tested during the scoping studies for two major composites are shown in Tables 1 and 2, respectively.

Table 1 – Head assays for the Reko Diq composites tested using conventional flotation process

Samples	Cu (% total)	Cu (acid soluble; g/t)	Au (g/t)	Mo (g/t)	S (% total)	S (% sulphide)
Comp 1	0.58	179	0.61	72	4.3	2.0
Comp 2	0.52	128	0.68	28	3.5	1.6

Table 2 shows that the site water resulted in a lower copper and gold recoveries, which was attributed to a pH buffering effect leading to very high lime consumption while depressing pyrite to target a high pH of 11-12 in the copper cleaner circuit. Also, due to high lime addition, gypsum precipitation was observed resulting in poor flotation selectivity.

Table 2 – Locked cycle test results using site water and tap water for the Reko Diq composites

	Concentrate Mass pull (%)	Final Concentrate (Cu %)	Recovery % Cu	Final Concentrate Au (g/t)	Recovery % Au
Comp 1 Tap water	2.0	29.4	94.4	13.2	88.5
Comp 1 Site water	1.9	28.4	92.5	12.2	80.5
Comp 2 Tap water	1.7	29.5	94.5	17.3	82.9
Comp 2 Site water	1.7	29.5	90.4	17.4	77.2

An intensive optimization study was carried out using different reagent schemes to improve flotation performance using site water. Of all the schemes tested, an addition of 20 g/t of NaCN in the cleaner circuit improved the flotation results but still could not replicate the results of tap water. The cyanide scheme was selected as the best scheme for carrying out further locked cycle testing on various mineralogy composites representing major lithology and alterations. Most of these composites performed well except for the samples representing Sericite-Clay-Chlorite (SCC) that showed poor copper recovery of 75%. The proportion of SCC in the deposit was initially considered low (less than 10%) but this increased to greater than 40% with the re-categorisation of the ore deposit during the pre-feasibility study. This meant that the overall life-of-mine metal recovery was significantly lower with the conventional copper flotation process using Reko Diq site water, resulting in an unfavourable economics and a major setback for the project.

Development of the AMBS Process

Tethyan requested Barrick's flotation expertise to provide support in developing a solution to the problem. A proven five-step approach was rigorously applied to develop a solution and the in-depth understanding and concepts developed from bench scale test work were transferred all the way to plant implementation. This approach will not be discussed here and is described elsewhere (Gorain, 2013; Gorain and Kondos 2015). This paper will only focus on step 1 of this approach, which is to understand the problem through an in-depth investigation.

Extensive R&D work included detailed mineralogy, water chemistry evaluation, surface analysis and testing of various reagent schemes to obtain a deeper understanding of the issues. The main conclusions from this optimization work were as follows:
- Addition of lime is detrimental to flotation due to precipitation of gypsum with site-water
- Metabisulfite (MBS) as pyrite depressant was superior to all other pyrite depressant reagent schemes tested including cyanide
- Flotation performance improved significantly with aeration after regrind
- A new Aeration-MBS (AMBS) scheme was developed that resulted in significantly better recovery and concentrate grade with no need for lime and cyanide.

The AMBS process involves a specialized aeration process after regrinding of rougher concentrates along with recycled cleaner circuit streams for a certain duration followed by staged addition of sodium metabisulfite (MBS) in the cleaners without the need for any pH adjustment. The fundamental reason for including the aeration step is to improve the kinetics of copper minerals and not oxidation of pyrite as commonly believed. The aeration step also provides the optimum electro-chemical potential (Eh) and slurry chemistry to make it possible for the MBS to depress pyrite without the need for any lime addition. This combination of aeration with MBS without any addition of lime is a novel way of separating copper minerals from pyrite at natural pH when site water poses flotation chemistry problems.

The AMBS process was rigorously evaluated on various ore types in bench scale test work using open cleaner and locked cycle tests during the pre-feasibility study. Table 3 compares the results of the cyanide and AMBS schemes for three different ore types that were metallurgically complex. As shown in the table, the AMBS scheme gave significantly better flotation performance than the cyanide scheme.

Table 3 – Comparison of the locked cycle results for three ore types using cyanide and AMBS schemes

Samples	Schemes	Head Cu %	Concentrate Mass pull %	Concentrate Cu %	Recovery Cu %
A	AMBS	0.48	1.36	35.1	92.2
A	Cyanide	0.48	1.31	33.0	86.7
B	AMBS	0.53	1.62	35.6	91.1
B	Cyanide	0.53	1.73	34.9	88.4
C	AMBS	0.31	0.90	36.1	90.0
C	Cyanide	0.31	0.84	37.0	84.4

Tables 4 and 5 compare the locked cycle test results using the conventional lime/cyanide and the AMBS processes, respectively, for 16 different Reko Diq variability samples representing all major ore types. This was part of a major initiative during the feasibility study to validate the robustness of the AMBS process. Details of the ore types are not discussed here mainly to limit content that are not relevant to the main theme of this paper.

Table 4 – Locked cycle test results for the 16 different Reko Diq variability samples using the cyanide scheme (feasibility study)

Comp No	Ore types	% of ore deposit	Head Cu %	Concentrate Cu %	Mass Pull %	Recovery Cu %
1	PFB1 - POT	5.0	0.59	28.3	1.90	91.7
2	PFB1 - MIX	2.0	0.42	28.2	1.08	72.2
3	PFB2 - POT	5.0	0.61	32.9	1.51	80.9
4	PFB2 - MIX	3.0	0.51	31.3	1.41	86.1
5	VIN - POT	3.0	0.69	30.5	1.88	83.6
6	VIN - MIX	4.0	0.43	33.3	1.14	88.5
7	VIN -SCC	6.0	0.36	25.4	1.10	78.0
8	VFL - POT	5.0	0.67	29.8	2.01	89.5
9	VFL - MIX	7.0	0.60	34.0	1.59	89.9
10	VFL -SCC	9.0	0.61	32.2	1.70	90.1
11	PFB1 - SCC	4.0	0.56	29.8	1.66	87.5
12	PFB1 - SCC	11.0	0.51	32.9	1.37	88.8
13	PFB2 - SCC	5.0	0.56	26.7	1.64	81.0
14	VIN – MIX 2	1.0	0.64	31.0	1.73	84.5
15	VIN –SCC 2	8.0	0.52	28.7	1.42	78.5
16	VFL – MIX 2	4.0	0.53	30.7	1.49	87.1
	Weighted average	**100.0**	**0.55**	**30.6**	**1.53**	**85.7**

Table 5 – Locked cycle test results for the 16 different Reko Diq variability samples using the AMBS scheme (feasibility study)

Comp No	Lith - Alt	% of ore deposit	Head Cu %	Concentrate Cu %	Mass Pull %	Recovery Cu %
1	PFB1 - POT	5.0	0.60	33.7	1.66	93.6
2	PFB1 - MIX	2.0	0.44	33.6	1.20	92.1
3	PFB2 - POT	5.0	0.63	36.6	1.66	92.2
4	PFB2 - MIX	3.0	0.51	34.4	1.38	93.3
5	VIN - POT	3.0	0.70	34.0	1.98	93.8
6	VIN - MIX	4.0	0.44	34.7	1.09	91.3
7	VIN -SCC	6.0	0.41	29.0	1.32	92.6
8	VFL - POT	5.0	0.75	37.6	1.09	87.6
9	VFL - MIX	7.0	0.60	37.4	1.49	91.0
10	VFL -SCC	9.0	0.57	33.3	1.65	90.4
11	PFB1 - SCC	4.0	0.60	34.7	1.58	91.7
12	PFB1 - SCC	11.0	0.48	33.2	1.44	92.4
13	PFB2 - SCC	5.0	0.56	24.8	2.11	90.6
14	VIN – MIX 2	1.0	0.60	33.7	1.78	93.5
15	VIN –SCC 2	8.0	0.51	32.0	1.43	90.3
16	VFL – MIX 2	4.0	0.53	36.8	1.30	90.1
	Weighted average	**100.0**	**0.55**	**33.6**	**1.50**	**91.4**

Both Tables 4 and 5 show that the AMBS scheme gave significantly better results than the cyanide scheme for almost all ore types. The AMBS scheme worked significantly better for problematic ores such as PFB1-MIX and VIN-SCC. On average, copper recovery was about 6% higher with better copper concentrate grade for the AMBS scheme based on the locked cycle test program. These results were validated further using pilot scale testing for different composites representing life-of-mine. The pilot scale results will not be discussed in this paper and is best presented separately to avoid a lengthy paper.

The AMBS process improved project economics due to significant increase in copper revenue as the life-of-mine copper recovery was almost 6% higher for the AMBS scheme than for the cyanide scheme.

Application of the AMBS Process to Other Barrick Projects

With the success of the AMBS process for Reko Diq, this technology was evaluated for various Barrick projects to identify opportunities to improve project economics. For some of the projects in Chile, evaluation of this technology with the use of raw sea water was gaining momentum due to challenges encountered in making fresh water available for these projects. Table 6 demonstrates the benefit of the AMBS process for a major copper-gold deposit in Chile using sea water.

Table 6 – Flotation results of the AMBS and lime schemes using site and sea water

Water Type	Lime scheme			AMBS scheme		
	Concentrate Cu%	Recovery% Cu	Recovery% Au	Concentrate Cu%	Recovery% Cu	Recovery% Au
Site water (locked cycle)	27.6	79.5	62.0	31.2	87.3	62.0
Sea water (locked cycle)		poor flotation		30.2	86.6	58.7

Table 6 shows that the AMBS process improved copper recovery by about 7% with significantly better concentrate grade. Importantly the flotation performance of the lime scheme with sea water was poor due to buffering of slurry pH at around 9 resulting in its inability to depress pyrite. The AMBS scheme at natural pH, however, did not show a significant detrimental effect on flotation performance. This confirms the robustness of the AMBS scheme in depressing pyrite at natural pH even for poor quality water as previously observed for other ore bodies.

This AMBS process was further tested for another challenging project in Chile and Argentina. The problem is that the ore contains a significant amount of soluble copper and iron minerals resulting in a slurry pH of 1.5 to 3 after primary grind. A significant amount of lime is required with the conventional lime flotation scheme resulting in precipitation of various species with a negative impact on flotation selectivity. A major test program was initiated on five major ore types along with two composites to optimize the flotation performance using the AMBS scheme. After an initial open cleaner circuit optimization, a large number of locked cycle tests and major piloting work were carried out on individual ores and composites. Table 7 summarizes the overall recovery with the AMBS process when compared with the conventional lime based process.

Table 7 – A summary of the overall recovery with the AMBS and lime schemes for complex a copper-gold-silver ore

	Recovery% Cu	Recovery% Au	Recovery% Ag
Lime scheme	80.0	83.5	84.3
AMBS scheme(pilot)	86.9	92.8	84.5

Table 7 shows the AMBS scheme gave significantly better overall metallurgical performance than obtained with the lime based flotation scheme for a similar copper concentrate grade. These ores contain a significant amount of refractory gold and therefore improving gold recovery in copper flotation was found to be beneficial as the pyrite associated gold was difficult to leach in the flotation tailings. It is important to note that the AMBS scheme worked well even at a low pH of 4.5 despite the complex solution chemistry of flotation feed.

The AMBS flotation process has now been validated for a number of ore types. The key feature of this process is that the depression of pyrite in cleaner flotation is possible at a natural pH of the ore without the need for conventional pyrite depressants such as cyanide and lime. The AMBS process was effective even for complex copper, copper-gold and copper-gold-silver ores with a high iron to copper ratios. Importantly, the AMBS process also works well when poor quality water, such as brackish or high salinity water, is used in the flotation process. In poor quality water, the lime scheme is not effective in depressing pyrite as obtaining a high slurry pH of 10 to 11 is difficult due to pH buffering effects.

Commercial Application at an Operation in South America

The AMBS process is being commercially used successfully by another mining company with raw sea water since 2012 successfully.

This company encountered difficulties in upgrading the copper concentrate in the cleaner circuit when seawater was used with conventional lime based process. With the AMBS technology, however, no such detrimental effect was observed even at natural pH in the cleaner circuit. In addition, higher recoveries of molybdenum were observed using the AMBS technology. Figure 1 shows a photograph of this operation in South America.

Figure 1 – Flotation plant using the AMBS process with raw sea water at a South America operation

Plant Application at Jabal Sayid Operation

Jabal Sayid is a copper operation based in Saudi Arabia and is now a joint venture of Barrick and Ma'aden. The motivation for using the AMBS process here was to assess the potential of Metabisulfite (MBS) as an alternative to cyanide and lime in depressing pyrite. The use of cyanide was a significant risk for the project due to permitting issues. Since the only water available for Jabal Sayid was municipal sewage water, which meant that the use of lime would quickly result in scaling issues because of the requirement for recycling the concentrate and tailing thickener overflow water. This would also be problematic especially at the concentrate and tailings filtration areas requiring washing with weak acid instead of just water. Also obtaining large steady volumes of limestone was seen as a risk in Saudi Arabia.

When Barrick acquired the project with the acquisition of Equinox in 2011, the flotation plant has already been designed using conventional lime/cyanide based flotation scheme. By this time, the AMBS process has already been developed and naturally this technology was evaluated immediately while the permitting process was in progress.

Initial flotation tests by Barrick suggested that a natural pH during rougher flotation is the best without the need for any depressant. Any aggressive depression of pyrite in the rougher was counter-productive due to high losses of copper, as there is a significant amount of pyrite locked with copper minerals typically due to a coarser primary grind P_{80} of 150 micron. The key was to apply a suitable pyrite depressant strategy in cleaner flotation after regrinding where a significant proportion of pyrite is liberated from copper minerals. This enables maximization of copper recovery in the cleaners with a high copper concentrate grade as long as an appropriate pyrite depressant regime is used. The results of the flotation tests carried out with cyanide and AMBS schemes on the Lode 2 master composite are shown in Figure 2.
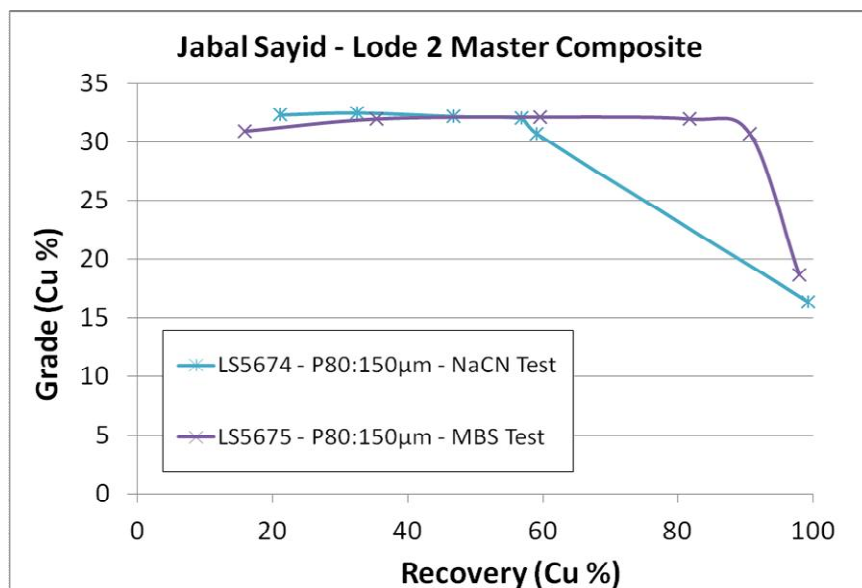
Figure 2 – Copper grade and recovery relationships for the cyanide and the MBS schemes on a Jabal Sayid Lode 2 master composite sample.

These tests suggest that the MBS scheme is able to depress pyrite very well along with a high copper recovery of about 91% @ 33% Cu concentrate grade. The cyanide scheme showed about 60% Cu recovery @ 31% Cu concentrate grade. Figure 2 shows that the depression of pyrite is significantly better for the MBS scheme. These preliminary tests suggest that the MBS scheme can achieve similar or better cleaner flotation performance than possible using cyanide. Locked cycle tests were carried to confirm these findings.

After some validation work, the AMBS process has now been implemented at the Jabal Sayid operation requiring no lime and cyanide to depress pyrite. The AMBS process is suitable for high pyrite ores at Jabal Sayid. The plant is now operational since August 2015, and a photograph of the flotation plant using the AMBS technology is shown in Figure 3.

Figure 3 – Flotation plant using the AMBS process at Jabal Sayid Copper operation in Saudi Arabia

Understanding the AMBS Process

Further to the development of this AMBS technology driven by an immediate need for a robust solution for a major challenging project, it was felt necessary to obtain an in-depth understanding of the process for extending its use on various other challenging ore types. A research program was initiated at the Julius Kruttschnitt Mineral Research Centre (JKMRC) to understand the fundamentals of the AMBS process. As part of this work, a literature review was conducted (Nguyen et al, 2014) and a summary of the review is presented here.

Flotation with Sea Water

The effect of seawater on flotation performance has been recently investigated by some researchers and many of the findings tend to corroborate well with the experiences obtained during development of this AMBS process. Castro (2012) suggested that the two most important chemical factors of seawater that may affect the flotation processes are known as the buffering effect of seawater and the precipitation of secondary ions at alkaline pH with the depressing effect on flotation of some sulphide minerals. Bıçak et al. (2012) stated that increased froth stability can be obtained more easily in seawater with relatively lower amount of frother required in comparison with tap water due to the high ionic strength of seawater. This agrees with the conclusion from various earlier studies (Laskowski, 1966; Pugh et al, 1997) and the observations we made during the AMBS development work.

While lime is widely used as a mean to control pH for pyrite depression in copper flotation using fresh water, in the case of sea water, added OH^- ions from lime are consumed by other reactions resulting in significant higher dosage of lime required to reach to the desired alkaline pH, as demonstrated in Figure 4.
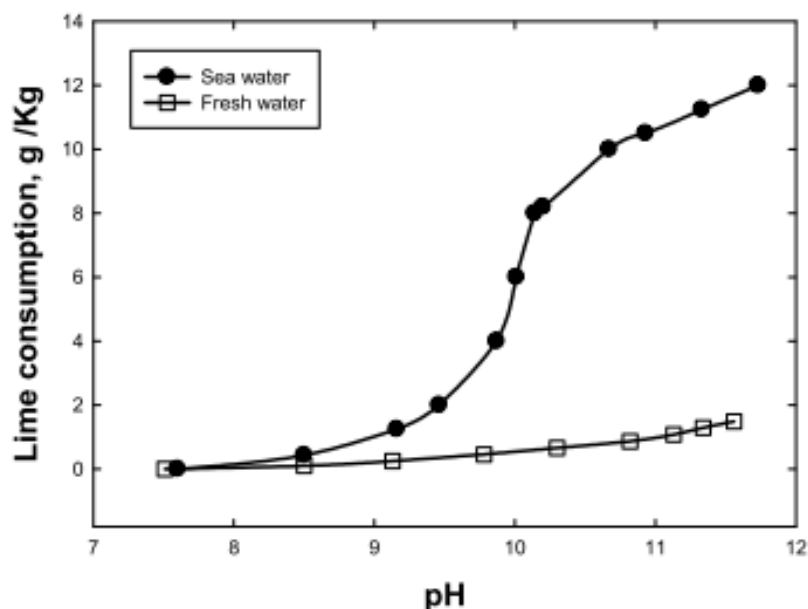
Figure 4 – Lime consumption in rougher flotation as a function of pH adjusted by lime for a copper ore floated in fresh water and sea water (Castro, 2012).

The buffering effect of sea water is known to be due to the presence of the couples carbonate / bicarbonate ions (HCO_3^- / CO_3^{2-}) and boric acid / borate ions ($B(OH)_3$ / $B(OH)_4^-$) (Pytkowicz & Atlas, 1975). But the most important contribution to the measured effect is deemed to come from the precipitation of $Mg(OH)_2$, as the solubility product of magnesium hydroxide is much smaller than the solubility product of calcium hydroxide and therefore any introduction of lime must initiate the precipitation of magnesium hydroxo-complexes and magnesium hydroxide in seawater (Castro, 2012). Figure 5 shows the concentration of both Ca^{2+} and Mg^{2+} ions in seawater when its pH is increased by lime addition.
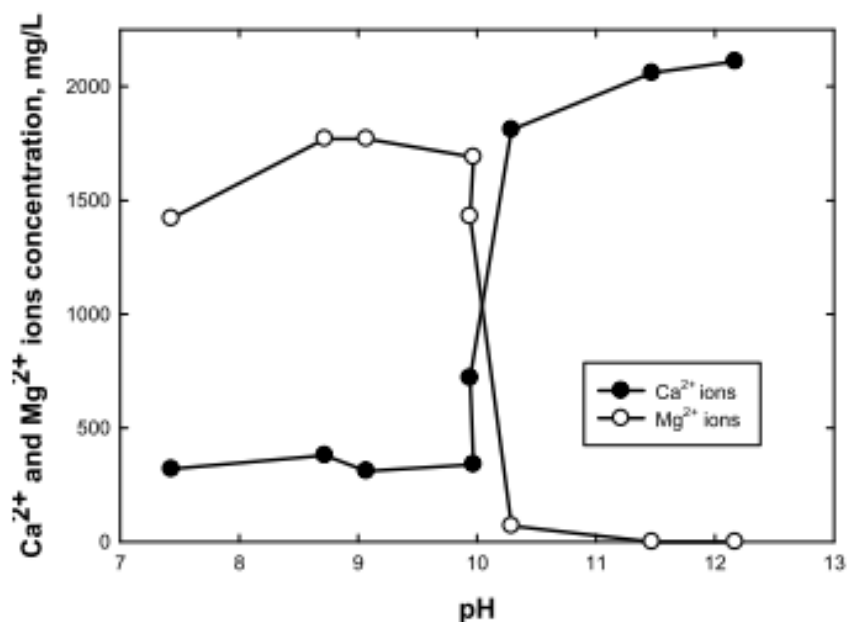

Figure 5 – Effect of addition of lime on concentration of Ca^{2+} and Mg^{2+} ions in sea water (Castro, 2012)

This agrees with the previous findings by Parraguez et al. (2009) when they suggested that the formation of magnesium carbonates and magnesium hydroxide prevented the increase in pH values when lime was used.

They have suggested the reason for lime to be less effective as a pyrite depressant when seawater is used in flotation is because of the pyrite surface modifier, Ca^{2+}, is consumed in part of the chemical reactions with various mineral species instead of being consumed entirely by the surface of pyrite.

Barrera & Cerna (2009) and Parraguez et al. (2009) agreed with the conclusion that pyrite activation can become an issue and can have negative impact on the final concentrate copper grade when seawater is used due to dissolution of small amounts of copper which in turn activates pyrite.

The observation during the AMBS process development to depress pyrite at natural pH was also observed by Bulut et al. (2011). According to Bulut et al. (2011), this pronounced depressing effect of sodium metabisulphite at natural pH was observed with both pure pyrite and pyritic copper ore containing of approximately 50% pyrite. This is an important observation and has implications for treating ores with very high pyrite content.

Bıçak et al. (2012) reported that for water containing higher concentrations of thiosulphate (approximately 1,200 ppm) and sulphate (approximately 1,700 ppm) ions, the true flotation of pyrite decreased. This indicates the depressive effect of the sulphoxy species in the pulp. It was believed that the thiosulphate and sulphate ions can counteract the activation of pyrite with dissolved copper ions when seawater is used. Lehmann et al. (2000), on performing a study on pure pyrite, suggested that the presence of chloride ion, which is abundant in seawater, can reduce the flotation of pyrite by promoting the oxidation of an absorbed intermediate, believed to be the thiosulphate ion, producing from the reaction between sulphite ions and elemental sulphur, to soluble tetrathionate ion.

$NaHSO_3$ has been used as a flotation depressant for pyrite (Ikumapayi, 2010). However, the use of sulphoxy type depressants, such as sulphite, bisulphite, metabisulphite (MBS) and sulphur dioxide, to control the unwanted flotation of sulphide minerals in mildly alkaline environments is generally considered to be as the result of the sulphite SO_3^{2-}, or thiosulphate ions, $S_2O_3^{2-}$ (Khmeleva et al., 2003). Ikumapayi (2010) suggested that the reduced sulphoxy anions will be much stronger bound to the sulphide surface compared with the sulphate anions that are directly adsorbed through ion exchange / outer-sphere complexation, thus competing more efficiently with collectors for adsorption sites on sulphides, which may strengthen the depressing effect of sulphite. This effect, once understood, can open a new cost effective approach to selectively regulate surface properties of sulphides for more effective selective flotation of valuable sulphide minerals over sulphide gangue minerals.

The Mechanism for Copper Flotation with Sulphoxy Compounds

It was believed that under the conditions of pH 7 and air purging, while sodium bisulphite can depress pyrite by enhancing the formation of oxide and hydroxide species, it has very limited impact on the surface chemistry or floatability of chalcopyrite (Khmeleva et al., 2003). Ross and Van Deventer (1985) suggested that the sulphite ion also has a cleaning effect on chalcopyrite to increase chalcopyrite recovery, although this was not proved in their study. However, they noted that under the conditions studied in their experiments, milling in a steel mill followed by pre-aeration greatly improved the copper grades and copper-lead selectivity when sulphurous acid was used as pH regulator compared to milling in a ceramic mill. It was found (Houot & Duhamet, 1993) that the depressing effect of sulphite ions on chalcopyrite-pyrite flotation depends on the presence of Fe^{3+} ions released from grinding media.

Grano (1997) also studied the behaviour of sulphite ions the flotation of pure chalcopyrite and tended to agree with Houot & Duhamet (1985) suggestion that the effect of sulphite on chalcopyrite flotation strongly depends on the oxidation state of the chalcopyrite surface prior to sulphite addition. If the chalcopyrite has significant surface concentrations of adsorbed iron oxyhydroxide species, sulphite may

increase its flotation due to removal of the interfering iron oxyhydroxide via a mechanism involving reduction of surface ferric oxyhydroxide to more soluble ferrous species. However, if excess sulphite is added to the system, sulphite may decompose the sulphur-rich sub-layer resulting in low chalcopyrite flotation recovery. Grano also suggested that the cleaning action of sulphite could be reduced at pH > 7.5. He also proposed an Eh value of approximately + 170 mV which Fe(II) species would be more stable. Bulut et al. (2011) confirmed in their study that pyrite depression is more effective when metabisulphite was used at pH 6.5 compared to pH 10. This confirms the findings from the AMBS development work on various ores that pyrite could be effectively depressed at a much lower pH that normally used in the conventional lime based process.

Pre-aeration

The importance of aeration and pulp potential in the AMBS process has also been observed by other researchers. Pulp oxidation potential control is critical for effective control of selective flotation between pyrite and chalcopyrite when sulphoxy compounds are used, and an aeration conditioning step is therefore needed to maintain sufficient oxygen activity (Ross & Van Deventer, 1985, Shen et al., 2001, Khlemeva et al. 2003). Aeration conditioning may also be needed to restore oxidation potential with sulphoxy addition as the process can consume oxygen (Chandra & Gerson, 2009). It is likely that different oxygen flow rates are required for optimum mineral separation depending on the relative mineralogy in the feed and also on the activity of the pyrite contained in the ore (Owusu et al., 2014).

Raw seawater is ranked as the most economic source of water but its use in flotation requires in in-depth understanding of the various mechanisms involved such as the effect and interaction of sulphoxy compounds, aeration and dissolved ions in the seawater with respect to the mineralogy of the ore, pH and pulp potential (Barrera & Cerna, 2009). Once understood, this can open a new cost effective approach to selectively regulate surface properties of sulphides for more optimum flotation performance in saline water.

Intellectual property (IP) for the AMBS process

The intellectual property (IP) for the AMBS process is planned to be jointly managed by Barrick and possibly another mining company based in South America. This will help in preventing unsolicited use of this technology and will also allow successful transfer of technology to companies interested in its legitimate application for their projects and operations.

CONCLUDING SUMMARY

The AMBS flotation process has been developed to replace cyanide and lime conventionally used for depressing pyrite in various copper and copper-gold operations. The key feature of the AMBS process is that it is environmentally friendly and has no significant detrimental effect on flotation performance when poor quality water such as brackish or high salinity water is used. Moreover, the flotation performance and process economics of the AMBS process have been shown to be better than that for lime and cyanide based schemes even for some complex copper ores with a high pyrite to copper ratio. The literature review clearly points out the potential of this AMBS process but in-depth understanding of the principles is critical for its successful use.

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