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Cytec Solutions

**For Hydrometallurgy
and Mineral Processing**

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Letter From The Vice President

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All the best in 2008,

A handwritten signature in blue ink, appearing to read 'Joe Kozakiewicz'. The signature is stylized and fluid, with a long horizontal stroke at the end.

Joe Kozakiewicz
Vice President, Mining and Phosphine & Phosphorus Specialties

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Flowsheet Considerations For Copper-Cobalt Projects In The DRC

Dr. Douglas Flett, Stevenage, United Kingdom

Dr. Cyril Bourget, Technical Specialist, Cytec Canada Inc., Welland, Ontario, Canada

Owen Tinkler, EMA Regional Sales Manager, Cytec Industries Inc., Johannesburg, South Africa

Introduction

Currently there are a significant number of copper/cobalt projects under development in Africa, particularly in the Democratic Republic of Congo (DRC). These projects will use solvent extraction and electrowinning to recover copper. The technologies for the recovery of the cobalt are less well defined. A variety of options have been examined including sequential combinations of precipitation or solvent extraction to remove impurities and separate cobalt for production of a final product in either metal or chemical compound form. Final choice of flowsheet is quite open and will be influenced by the suite of impurities arising in the ore bodies involved in the individual projects and, to some extent, by what final cobalt product is required (i.e. an impure cobalt carbonate for sale to refiners, cobalt metal or high grade cobalt salts).

[Note: An extended discussion of these design issues can be found in the proceedings from the 2007 ALTA Conference on Ni/Co, Perth, Australia by Tinkler, Flett, and Bourget.]

Flowsheet Design

There are a variety of techniques and technologies to consider when formulating a flowsheet for treatment of a copper/cobalt ore. It must be emphasized that all ores are different and therefore a degree of tailoring of flowsheets will be required. However a number of common features emerge.

A schematic for a preferred processing route is shown in Figure 1. Although this includes

cobalt electrowinning it can obviously be readily adapted for production of high purity cobalt salts by inclusion of appropriate stripping and precipitation/crystallization steps in place of cobalt electrowinning. The resin ion exchange scavenge step is also included.

a) Leaching

Direct acid leaching of oxide copper/cobalt ores will be standard in all flowsheets. However, depending on the mineralogy of such ores, it is likely that a second stage leach will be necessary under reducing conditions, using SO_2 as the reductant, in order to maximize cobalt recovery to the final leach liquor. As such “refractory” cobalt is almost always associated with manganese, this means that manganese will also report to the final leach liquor.

Where sulfide ores are to be treated, concentration by flotation is standard practice. Leaching of such concentrates has traditionally been preceded by oxidative roasting. There are problems with the use of roaster technology through the formation of ferrites in the roaster calcine which can reduce the amount of cobalt recovered from acid leaching of the roaster calcine unless strong acid leaching is employed. A better, state-of-the-art, approach would be to pressure leach the sulfide concentrate which not only will result in higher cobalt recoveries but also result in elimination of much of the iron as haematite in the autoclave and generation of acid for use in leaching of oxidic material, thus reducing the need to generate acid in-situ from the burning of imported sulfur in an acid plant.

b) Copper solvent extraction

High grade copper cathode will be produced via solvent extraction and electrowinning. Selection of the appropriate extractant is dependent on the amount of copper in the leach liquor, the amount of manganese and how the secondary copper solvent extraction step for high copper recovery is to be carried out prior to purification of the cobaltiferous liquor in the cobalt refinery. Minimizing the level of copper in the raffinate from primary copper extraction is important to allow the secondary copper extraction stages to remove the remaining copper. Use of alkali to effect pH adjust in the secondary copper solvent extraction step may be essential but it should not be so great that the secondary copper extraction circuit runs the risk of incipient cobalt extraction (likely at pH values >4) which would lead not only to loss of cobalt but would also poison and degrade the hydroxyoxime. Although there are a number of options for the copper SX circuit, the optimum reagent formulation and circuit configuration can be determined using Cyttec's MINCHEM modeling program.

c) The cobalt refinery

The major activity in the cobalt refinery is the removal of impurities prior to the production of the final cobalt product be this high purity cobalt metal by electrowinning or the production of high purity cobalt salts. The impurities

that have to be dealt with in the DRC copper/cobalt projects are Fe, Al, U, Zn, Cd, (Cu), Mn, Ni, Ca and Mg.

Iron and Aluminum

Iron and aluminum are traditionally removed by hydrolytic precipitation. An immediate issue arises with regard to the location of this step within the flowsheet. Should it be sited before or after the secondary copper solvent extraction step?

As the raffinate from primary copper solvent extraction is acidic it is argued that it makes sense to put the iron removal step before secondary copper solvent extraction so that secondary copper solvent extraction can proceed from a relatively high pH base post iron precipitation. If lime or limestone is used for iron removal then, as practiced currently, a two stage precipitation will be necessary in order to remove iron to the desired level i.e.<1 ppm.



The first precipitation step would be carried out at around pH 3.5 while the second would be carried out at around pH 5-5.5 at which pH aluminum would also be precipitated. This precipitate would contain appreciable quantities of Co (1) and must be recycled within the flowsheet to minimize cobalt losses. At this pH the risk of co-extracting some cobalt with the copper in the secondary copper solvent extraction step would be high.

Provided that the primary copper solvent extraction step provides a raffinate containing just a few g/l of copper in the raffinate then adjustment of the pH to ~ 2.5 and the use of a strong copper extractant such as ACORGA® M5640 copper extractant would permit a final copper level in the raffinate of ~50 ppm or less without further need for pH adjustment. Iron precipitation could then proceed and provide a barrier preventing cross contamination of subsequent downstream solvent extraction steps with entrained hydroxyoxime.

There is also a choice of technique with regard to iron precipitation. Lime or limestone is the traditional method which requires two stages at increasing pH to be effective as noted above. An alternative method involves the use of air/SO₂ as described by Zhang et al (2). This approach has the advantage of removing manganese as well, provided that the correct operating pH is chosen. From the work of Zhang et al, low concentrations of Mn(II) could be selectively oxidized and precipitated from Co(II) and Ni(II) at pH 3-4 with <1% co-precipitation of cobalt and nickel. However Co(OH)₃ is precipitated at pH values >4. Adoption of this method for

removal of Fe and Mn means that a further precipitation step is required to achieve complete removal of Al at around pH 5-5.5. This precipitate would have to be recycled within the flowsheet to minimize cobalt losses.

Zinc and Manganese

After iron elimination it is now necessary to remove zinc (and manganese if iron elimination is carried out by the limestone precipitation route). Both zinc and manganese can be removed by solvent extraction with DEHPA. However it is reported by Sole (3) that the decision in favor of air/SO₂ for iron and manganese removal in the work done by Anglo American on the Kolwezi Tailings project was because unacceptable losses of cobalt occurred at the pH values required for Mn co-extraction with zinc, thus needing enhanced scrubbing requirements. No doubt this depends on the level of manganese in the leach liquor in the first place.

Downstream cross-contamination of a CYANEX® 272 circuit must also be avoided as DEHPA will extract calcium and magnesium at the pH value for cobalt extraction and it also accelerates cobalt-catalyzed oxidative degradation of the diluent compared with CYANEX 272 (4), and has a much lower separation factor for cobalt from nickel although this is not of such great significance in the treatment of copper/cobalt ores. This means that the equipment for removal of entrained organic phase employed on the feed to any DEHPA solvent extraction circuit should also be considered on the raffinate leaving this circuit.

If manganese is to be removed by precipitation by the air/SO₂ method then it is possible to consider the use of CYANEX 272 for zinc removal instead of DEHPA. This has advantages in that it eliminates cross-contamination with any cobalt solvent extraction circuit that may be used for cobalt recovery downstream. It is also possible to remove co-extracted ferric iron with 150g/l sulfuric acid in the strip whereas 6 N HCl is required if DEHPA is used. It must be emphasized that, if DEHPA is used for both iron and manganese elimination, then co-extraction of calcium is inevitable and the use of sulfuric acid for zinc stripping is troublesome because of gypsum precipitation. After removal of zinc it may be necessary to polish the liquor using resin ion exchange to finally remove all traces of copper and zinc should there be any traces remaining.

Final Cobalt Separation

At this point, whichever techniques have been used, the cobalt liquor has been purified of Fe, U, Zn, Cu, and Mn (and possibly Ca) if DEHPA has been used to co-extract Zn and Mn. At this point there are further choices to be made with regard to the process flowsheet. The final step in the flowsheet before production of the desired cobalt product can be either precipitation of cobalt hydroxide with MgO or solvent extraction with CYANEX 272.

Precipitation: While limestone is currently the preferred precipitant at the cobalt refineries on the Zambian Copper Belt, this is not ideal as gypsum co-precipitates. On re-dissolution of the cobalt hydroxide the need for significant residue washing to minimize cobalt losses then

restricts the cobalt tenor achievable in the final cobalt liquor. The use of MgO in place of limestone gives a much cleaner precipitate in that there is no co-precipitation of gypsum and high cobalt tenors on re-dissolution of the precipitated cobalt hydroxide of up to at least 60 g/l cobalt are possible. However, as with the use of all such precipitants sourced from deposits located near to the refinery, care must be taken not to introduce impurities into the circuit that may be present in the precipitant itself.

An account of the use of MgO as a precipitant for cobalt and nickel has been published (5). However, the excess MgO present in the hydroxide precipitate product will report to the leach liquor on redissolution. This will be acceptable perhaps where the hydroxide prod-



uct is an intermediate to be sent to a nickel refinery for further processing but may pose problems when used for precipitation of cobalt in a cobalt refinery not least because of the high amounts of magnesium present in the precipitate, mostly presumably from unreacted MgO. Furthermore co-precipitated nickel will also report to the final liquor on dissolution of the precipitated cobalt hydroxide. This will have to be removed presumably by using a

manganese is oxidized at the anode to Mn^{4+} which results in precipitation of MnO_2 that can be physically removed. Tolerable levels of manganese in the recirculating electrolyte in a cobalt tankhouse are between 1.5-2.0 g/l. Thus there would seem to be a limit on the amount of unreacted MgO that the precipitation route can cope with while the use of solvent extraction with CYANEX 272 provides significant flexibility with regard to the co-extraction of

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chelating cation exchange resin or it will contaminate the final cobalt product be it a cobalt salt or cobalt metal. Unfortunately there are no published comparative cost data for the MgO precipitation re-dissolution route versus the CYANEX 272 solvent extraction route in order to provide a basis for selection. However the ability to separate cobalt from Mg, Ca and Ni in one step would seem, a priori, to give the technological advantage to the CYANEX 272 solvent extraction option.

It is not clear what could be done to remove the magnesium when cobalt salts are to be produced via the MgO precipitation route. For the electrolytic production of cobalt metal neither manganese nor magnesium are reduced to the metal at the potential for cobalt reduction. Magnesium is usually maintained at ~10 g/l in the cobalt electrolyte by a controlled bleed from the electrowinning circuit while

Mn and Mg together with the cobalt and the required degree of scrubbing of the loaded organic phase.

Solvent Extraction: Solvent extraction with CYANEX 272 will effectively separate the cobalt from Ni, Mg and Ca. The solvent extraction step using CYANEX 272, provides the best interface with cobalt electrowinning. It also interfaces easily with the production of cobalt salts as stripping is equally effective using HCl or HNO_3 instead of H_2SO_4 and there are no stability problems with CYANEX 272, in the presence of such acids. Alternatively precipitation of high purity cobalt carbonate as an intermediate to the production of other cobalt salts is easy.

There is a potential issue dealing with the sodium sulfate produced when cobalt solvent extraction is selected. Crystallization and sale

may be an option if a local market is available and efficient crystallization process is established. Disposal to tailings dams may be considered where annual evaporation rates are favorable which does not seem to be the case at the DRC locations of the projects although there would appear to be no such problem on the Zambian Copper Belt. Discharge to water courses is prohibited. The situation with regard to disposal of magnesium sulfate produced if the MgO precipitation route is different as magnesium sulfate may be limed and sent to tailings. The use of ammonia instead of NaOH as the alkali in the solvent extraction route results in the production of ammonium sulfate which can be treated by lime addition in the so-called “lime boil” process to produce ammonia for recycle and gypsum for disposal. In the past this process has not been favored because of excessive gypsum scale problems, high energy costs, etc. However there are claims that the process has been much improved and that it is now “fit for purpose”.

Conclusions

For the best results where high purity copper and cobalt products are required, both copper and cobalt solvent extraction are essential components of the flowsheet for the copper/cobalt projects in the DRC. Other options within the flowsheet such as iron and manganese removal await definitive engineering design for the air/SO₂ option otherwise the option employing DEHPA for removal of both zinc and manganese will have to be seriously considered together with all the negative implications arising in the use of this step. If the use of DEHPA can be avoided then CYANEX 272 can be used for zinc removal

thus removing the need to use HCl for stripping. Comparative costs are required to provide a proper basis for choice between MgO precipitation of cobalt hydroxide and cobalt solvent extraction with CYANEX 272, although technologically the selection of CYANEX 272 for cobalt solvent extraction rather than MgO precipitation is well justified. A satisfactory solution for the disposal of the sulfate salts produced in the process has to be found.

Finally, as producers of both ACORGA copper extraction reagents and CYANEX 272, Cytec offers a complete solution to the solvent extraction requirements for the DRC copper/cobalt projects.

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Kathy Sole, Chief Metallurgist, Anglo Research, a division of Anglo Operations Limited, Johannesburg, South Africa

Introduction

In copper solvent extraction (SX), the two main classes of commercial extractants employed today are ester-modified aldoximes and aldoxime:ketoxime mixtures. Ester-modified aldoximes are characterised by strong copper loadings from high acid ($\text{pH} < 2$) solutions, weaker stripping by conventional acid strength electrolytes, and excellent selectivity for copper over iron. Ketoximes are weaker extractants that operate better under weaker acid conditions, have poorer selectivity (copper over iron), but slightly higher hydrolytic stability.

In most North and South American SX operations, high copper selectivity is an important consideration in the choice of extractant, tending to favour the selection of modified aldoximes. In Africa and Australia, however, many plants treat leach liquors that contain significant amounts of manganese but little iron. Unlike iron, manganese is not chemically extracted by oximes, but small amounts of manganese are transferred from the leach liquor to the tank house electrolyte via entrainment (physical carryover of droplets of the leach liquor in the organic phase).

In the tank house, manganese reporting to the electrowinning (EW) cells can be oxidised at the anodes to Mn(III), Mn(IV) or Mn(VII), creating highly oxidising species that are then present in the spent electrolyte returned to the SX strip circuit. This contributes to degradation of the SX extractant and diluent, ultimately leading to increased organic losses, deterioration in phase separation, increased crud formation, and lower organic loading capacity.

Industry convention indicates that the Fe:Mn mass ratio in copper electrolytes should be maintained at $\sim 10:1$ to ensure that all Mn remains in the stable divalent state. For this reason, an increasing number of operations add ferrous iron to the electrolyte, usually as FeSO_4 or by passing the electrolyte over scrap iron. A more recent trend has been towards the choice of ketoxime-based extractants that are less selective for iron particularly where manganese is present in the leach liquor.

A new SX reagent, ACORGA® LS4202, designed by Cytec, now offers the possibility of tailoring the iron co-extraction so that copper selectivity can be manipulated to maintain an appropriate Fe:Mn ratio in the electrolyte. ACORGA LS4202 is based on ACORGA® M5774, so the other advantages of ester-modified aldoximes are maintained, while ensuring that sufficient Fe is transferred to the electrolyte, to offset the corresponding Mn transfer by entrainment.

Anglo Research, as an independent contractor with international SX credibility, carried out a continuous integrated closed-loop SX-EW pilot-plant trial to compare the copper- and iron-transfer characteristics of ACORGA LS4202 with those of two of the most widely used extractants, ACORGA M5774 and LIX® 984N (an equivolume blend of C₉ aldoxime and ketoxime).

Experimental

The extractants used were ACORGA LS4202, ACORGA M5774, and LIX 984N, each dissolved in Shellsol 2325 diluent. Since LIX 984N transfers slightly less copper per unit

volume, ACORGA LS4202 and ACORGA M5774 were used at 20 vol.% concentration, while LIX 984N was employed at 21.5 vol.%, thereby ensuring that copper transfer to the

organic phase was equivalent for the three systems. The PLS was supplied from a Zambian operation, having the average composition of 6.5 g/l Cu, 0.16 g/l Fe, 0.45 g/l Mn, pH 2, EMF 640 mV.

Table 1 Pilot Plant Operating Conditions

| Circuit | Parameter | Value |
|-----------------------|------------------------------------|----------------------|
| Extraction | PLS flowrate | 140 ml/min |
| | Organic flowrate | 170 ml/min |
| | Number of stages | 2 |
| | Mixer O:A | 1.2 |
| | Mixer residence time | 3 min |
| | Continuous phase | Organic |
| Stripping | Electrolyte flowrate | 70 ml/min |
| | Number of stages | 2.4 |
| | Advance O:A | 2 |
| | Mixer residence time | 3 min |
| | Continuous phase | Organic |
| Electrowinning | Advance electrolyte | 48 g/l Cu |
| | _Cu across EW | 13 g/l Cu |
| | Single-pass _Cu | 4 g/l Cu |
| | Recirculating electrolyte flowrate | 214 ml/min |
| | Current density | 220 A/m ² |
| | Current | 45 A |
| | Cell voltage | 2.0 V |

The flowsheet comprised two extraction stages and one strip (2E-1S) in the SX circuit, integrated with an EW circuit. A photograph of the plant is shown in Figure 1. The design operating conditions are summarized in Table 1.

The closed-circuit testing was simultaneously run for ten days with each extractant formulation. Flow rates were measured hourly. Physical parameters (organic depth, mixer O/A, continuity, etc.) were monitored throughout the run and metallurgical profiles were taken every eight hours and measured by inductively coupled plasma optical emission spectroscopy (ICP-OES).

Results

Copper Transfer

As designed, very similar loading performances were seen for the three systems. The modified aldoxime-based extractants showed slightly higher copper transfer.

Figure 1
Pilot Plant Unit: Three side-by-side closed circuit SXEW operations.



Table 2 Summary of Copper Transfer Data

| Parameter | ACORGA LS4202 | ACORGA M5774 | LIX 984N |
|--------------------------------|---------------|--------------|----------|
| Aqueous Cu Transfer | | | |
| PLS Cu (g/l) | 6.5 | 6.5 | 6.5 |
| E2 Raffinate Cu (g/l) | 0.36 | 0.41 | 0.50 |
| % Cu Recovery | 94.5 | 93.7 | 92.3 |
| Organic Cu Transfer | | | |
| Loaded organic Cu (g/l) | 8.93 | 9.30 | 9.11 |
| Stripped organic Cu (g/l) | 3.85 | 4.28 | 4.17 |
| v/o extractant | 20 | 20 | 21.5 |
| Net Cu transfer (g/l Cu / v/o) | 0.25 | 0.25 | 0.23 |

Transfer of Impurities to Electrolyte

The PLS composition remained constant throughout the trial, however the concentrations of all species in the electrolyte increased in an approximately linear manner with running time (Figures 2 and 3). It is well known that species such as Al, Si, Ca, Mg, and Mn are not chemically extracted by oximes, so their transfer through the circuit occurred by physical entrainment of the PLS in the LO, followed by subsequent transfer to the electrolyte in the strip circuit. The concentrations of these elements in the electrolyte were monitored throughout the test to determine an average % PLS entrained into the electrolyte for each extractant system.

Figure 2 Total Iron Transfer to Electrolyte

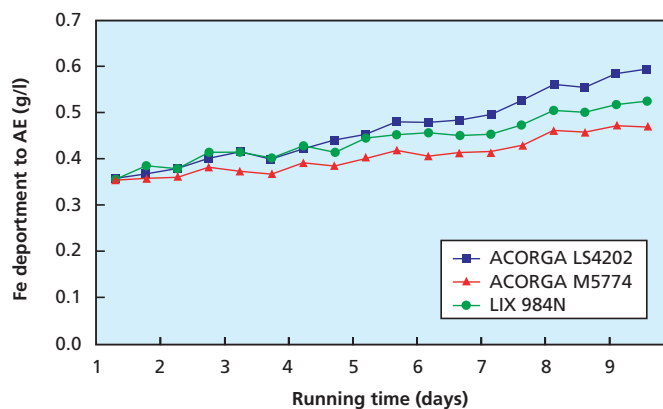


Figure 3 Transfer of Impurity Elements to Electrolyte

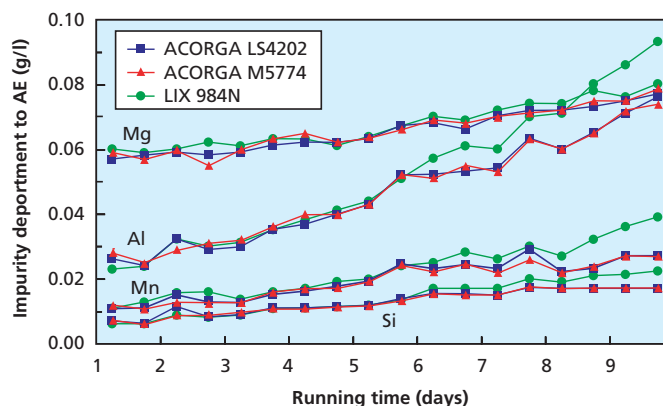


Table 3 Fe Transfer Summary

| Parameter | ACORGA LS4202 | ACORGA M5774 | LIX 984N |
|--|---------------|--------------|----------|
| Average % PLS entrainment from physical transfer (based on Ca, Mn, Mg, Al, & Si) | 0.0159 | 0.0168 | 0.0211 |
| Total Fe carry-over into electrolyte, physical and chemical (% of PLS concentration) | 0.4100 | 0.2139 | 0.2210 |
| Fe:Mn transfer ratio (based on PLS: 0.16 g/l Fe, 0.45 g/l Mn) | 9.2 | 4.5 | 3.7 |

* Entrainment as % of PLS = average mass/hour transfer into electrolyte as compared to PLS, expressed as a percent

In contrast to the above elements, iron is carried across to the electrolyte by both physical and chemical means, as trace quantities of Fe(III) are co-extracted by oximes. Ketoximes show less selectivity against iron than aldoximes: Figure 2 confirms that LIX 984N transferred more iron than ACORGA M5774. Although ACORGA LS4202 is an aldoxime-based extractant, the low-selectivity modifier allows increased transfer of iron. The relative iron transfer by entrainment and co-extraction are shown in Table 3. It is evident that the low-selectivity modifier allows the extractant to be tailored for specific chemical transfer of iron to the electrolyte.

Note: Interesting results were also observed with electrolyte EMF increasing despite maintaining Fe:Mn ratios greater than general industry recommendations to control it. For more information, please refer to the full paper available in the proceedings of the Copper 2007 conference.

Sole, K. C., Viljoen, K., Ferreira, B., Soderstrom, M., Tinkler, O., and Hoffman, L. (2007), Customising copper:iron selectivity in modified aldoxime extractants: Pilot-plant evaluation. In Proceedings Copper 2007, Volume IV, Book 2, The John E. Dutrizac Symposium on Copper Hydrometallurgy, Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, 3-14.

Summary

The trial was carried out on the Anglo Research Crown Mines site in November 2006, using a Zambian leach liquor. The trial was carried out successfully: the results generated were extremely positive (see Figure 2), confirming that the new reagent is capable of chemical transfer of greater amounts of iron than the comparative products without compromising the copper transfer characteristics. The comparison also showed that entrainment carryover of other impurities present in the leach liquor was lower when using modified aldoximes than ketoxime:aldoxime mixtures.

The results of this study were presented at the Copper 2007 conference in Toronto in August 2007.



Pilot-plant team (L-R): Kabelo Ledwaba, Boitumelo Molefe, Bronwynne Ferreira, Arinao Munyai, Ntumi Baloyi, and Karen Viljoen (kneeling).

Magnet Enhancer Technology for Impurities Separation in Kaolin Processing

SA. Ravishankar, Technology Manager, Mining Chemicals, Cytec Industries Inc., Stamford, CT

Introduction

Magnet enhancer technology (MET) combines magnetic separation and hydroxamate flotation approaches. The result is a process that allows higher brightness (and consequently more valuable) kaolin in a more efficient way. It also improves purification enough to allow processing of previously un-economical ore bodies. This performance can be achieved using a lower intensity magnetic field which allows lower capital.

Background

The focus of sustainability of future kaolin mining heavily relies on enabling technologies that conserve water and energy while minimizing waste generation. Manifesting challenges include improving yield, reducing energy consumption, beneficiating hard to process raw materials and simplifying process flows to result in more cost effective operations.

The kaolin beneficiation process, shown in figure 1, involves dispersion, size classification, removal of colored impurities and drying or slurry preparation for the end use. Improving removal of the colored impurities leads to a higher-brightness kaolin product. Higher brightness is one of the most sought-after properties on applications such as paper coating and paint. The processes for removing such impurities include magnetic separation, froth flotation and selective flocculation.

These processes are employed independently or in combination with each other. The magnetic separations separate ferro- and para magnetic impurities from dia-magnetic kaolin with the

help of high intensity cryomagnets. The flotation and selective flocculation processes exploit the physico-chemical differences between the surface properties where the impurities are selectively activated to render themselves for separation by adhering to carrier gas bubbles, as in flotation, or by attaching to a functionalized polymer. The major advantage with magnetic separation remains high yield and low reagent usage, however, limited success is achieved in the separation efficacy when finer impurities (<1 micrometer) are present in the feed. Use of stronger magnetic intensities during magnetic separation show only limited success. In addition, the diamagnetic colored impurities irrespective of size restrictions are not removed. Although both finer colored impurities and diamagnetic colored impurities are removed by flotation and selective flocculation, these processes require use and management of several chemicals. The performance of these chemical processes depends on process and feed variables, leading to quality variations. Post cleaning steps are then required that introduce cost and complexity in the process flow. In particular, poor yield from selective flocculation offers the least tolerant quality-yield tradeoff compared to other processes. There is a significant need to develop a robust process that encompasses the positive attributes of all three processes in a cost-performance effective manner.

During the past two decades, Cytec has documented through number of patents and industrial practices that the chelating surfactants such as alkyl hydroxamate offer significant advantages over conventional anionic collectors such as sulfonate and tall oil. The benefits of chelating surfactants in flotation and selective flocculation processes include:

- a) improving savings through substantial reduction in the energy input to the feed at the preconditioning stage,
- b) increasing the quality of the product by increasing the titanium removal potential and by being very selective to the impurity phase thereby substantially reducing the surfactant contamination and the corresponding side effects to the end products in subsequent applications,
- c) enhancing the yield across the process by avoiding inadvertent activation of kaolin,
- d) simplifying process by eliminating the number of cleaning steps required,
- e) reducing the number of chemicals addition, control and management, and
- f) enabling “hard to beneficiate” raw materials ultimately providing cost savings to the manufacturer.

hydroxamate chemistry in flotation and selective flocculation with magnetic separation. In the proprietary process, a tailor-made reagent is used to selectively bind to the impurities. This reagent combines magnetite for attraction to the magnet and hydroxamate (or other chemistry) for selectively attaching to the impurity targeted for removal. This system (impurity/reagent+magnetite) is separated from the kaolin when the low or high intensity magnetic field is applied.

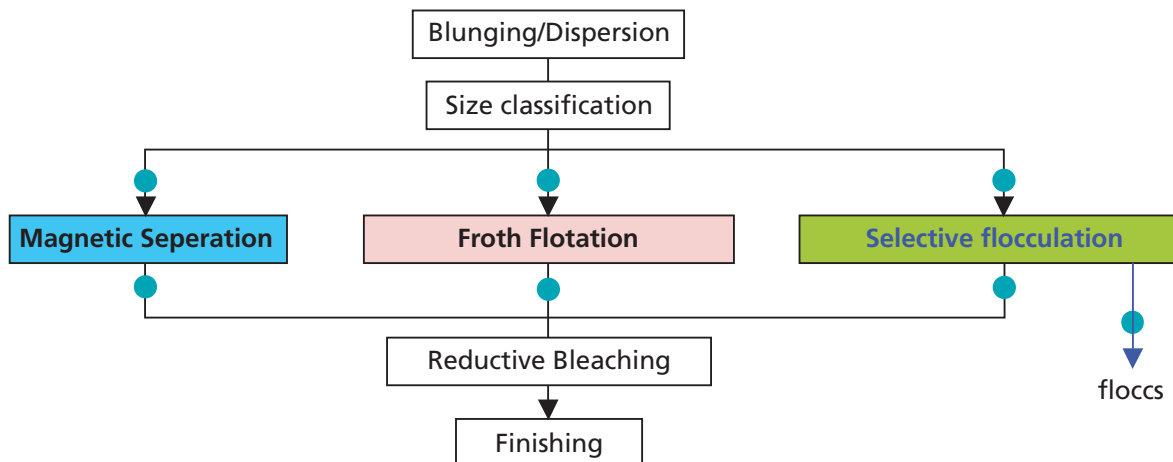
Application

Extensive test work suggests that MET can be applied to all the feeds and products in the kaolin beneficiation processes (see green dots in figure 1). The applications include: 1) achieving the product quality with the feeds that are not amenable to conventional magnetic separation, or 2) enabling MET as a replacement for flotation or selective flocculation (for colored impurities removal) from the existing beneficiation processes.

Magnetic Enhancer Technology

The magnet enhancement technology (MET) combines the best attributes of the

Figure 1: Process Flow of Kaolin Beneficiation



Magnet Enhancer Technology for Impurities Separation in Kaolin Processing

continued

The MET allows removing impurities at a very low magnetic field of 0.1-1 tesla providing a less capitol intensive technology and thus allowing the kaolin manufacturers to save energy while improving performance of existing low intensity magnets. Figure 2 indicates excellent performance (below the solid line at 0.6%) for TiO₂ removal (the colored impurities) in the product from 0.1 to 5.0 Tesla at the same reagent dosage and conditions.

Advantages of Magnetic Enhancer Technology:

- Extension of existing magnetic separation technology
- Comparable in quality and cost effectiveness to flotation and selective flocculation
- Adaptable to existing magnets with minimum capitol
- Process for removal of impurity minerals over wide size range - coarse to ultrafine kaolin
- Removes non-magnetic impurities
- High process yield
- Robust process
- Easy to use with minimal operator training

MET is a viable fine particle beneficiation process and a potential alternative to flotation and selective flocculation technology to achieve high brightness kaolin. When compared to existing technologies: magnetic separation (MS), flotation/selective flocculation (F/SF), MET emerges with synergistic advantages.

In summary, MET is a powerful technology for removing low level impurities from Kaolin.

It can also provide a basic approach for removing impurities from other mineral systems as well when combining the right combination of functionalized reagents with low-intensity magnetic separation.

Figure 2: MET: Efficient Impurity Removal With Low Intensity (Low Energy) Magnet Field.

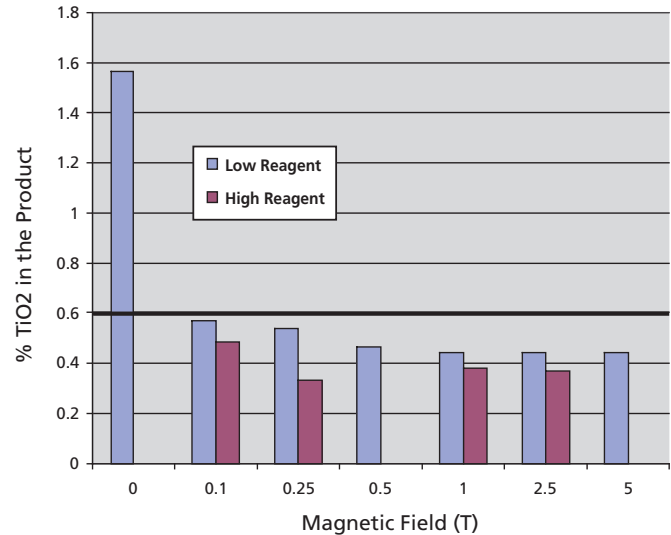


Figure 3: Comparison of Magnet Enhancer Technology

| Attributes | MS | F/SF | MET |
|---|--------|--------|--------|
| Product Cost | Green | Red | Yellow |
| Yield | Green | Yellow | Green |
| Chemical & Energy Usage | Green | Red | Yellow |
| Process Simplicity | Green | Red | Green |
| Post processing issues | Yellow | Red | Yellow |
| TiO ₂ rejection & Brightness Inc | Red | Green | Green |
| Operator Training | Green | Red | Green |
| Ability to Process Finer Particle | Red | Green | Green |
| Reserves utilization | Red | Yellow | Yellow |

Green = Performs very well Yellow = Performs adequately
 Red = Performs poorly (all relative to other options)

Ricardo Capanema, Marketing Manager, Mineral Processing, Cytec Industries Inc., West Paterson, NJ, USA
Wilfredo Perez, Global Applications Technology Group Manager, Mineral Processing, Cytec Industries Inc., Stamford, CT, USA
Francisco Garcia, Account Manger, Mineral Processing, Cytec de Mexico, Guadalajara, Mexico

Background

AEROPHINE® 3418A promoter is a unique, phosphine-based collector which was originally developed for the flotation of copper and activated zinc minerals. It has since been found to also be an invaluable (and often irreplaceable) collector in beneficiation of complex, polymetallic and massive sulfide ores. On these ores it provides very selective separations. It is highly effective for galena and precious metals, especially silver. Its main attributes are strong collecting power but with excellent selectivity against iron sulfides, inactivated sphalerite and penalty elements. On many ores, the dosage required may be considerably lower than that needed for traditionally-used non selective collectors. Other characteristics include:

- Low frothing characteristics, even on ores containing clay minerals.
- Fast kinetics.
- Good collection of coarse middling particles.
- Very stable. Resistant to hydrolysis and oxidation.
- Low environmental impact.

Further advantages have been observed in operating plants but are difficult to quantify. For example, AEROPHINE® 3418A promoter provides unusually rapid flotation kinetics and stable grade-recovery relationships. This, in turn, facilitates the optimization of circuit performance, particularly in computer controlled operations.

To better illustrate AEROPHINE 3418A promoter performance, two case studies will be presented. This data was obtained at plant trials and/or at facilities which now use AEROPHINE 3418A promoter on a commercial basis.

CASE I – Improved Copper Metallurgy

Ore from a chalcopyrite-sphalerite deposit was being milled at a rate of approximately 10,000 tonnes per day. The concentrator used a conventional flowsheet of copper flotation followed by copper sulfate activation and zinc flotation. After successful laboratory tests, AEROPHINE 3418A promoter was introduced for a full-scale ten-day plant trial. The standard mill promoter and frother were sodium amyl xanthate and MIBC, respectively.

The results of a typical test period are presented in Table 1.

Copper recovery was increased by approximately 8% and reagent dosage decreased by 30%. AEROPHINE 3418A promoter also induced minor improvements in zinc grades and recoveries. Zinc recovery in the copper concentrate and copper recovery in the zinc concentrate were essentially equal for both collectors. The improvement in copper metallurgy alone translates into a substantial monthly increase in the value of copper recovered at the mill.

Table 1. Case1: Improved Copper Metallurgy

| Parameters | AEROPHINE 3418A | Sodium Amyl Xanthate |
|----------------------------------|-----------------|----------------------|
| Heads % Cu | 0.97 | 0.84 |
| % Zn | 1.21 | 1.59 |
| Cu Conc. % Cu | 28.3 | 26.4 |
| Cu Tails % Cu | 0.10 | 0.17 |
| Cu Recovery % | 88.6 | 80.7 |
| Zn Conc. %Zn | 51.0 | 48.3 |
| Zn Tails % Zn | 0.24 | 0.32 |
| Zn Recovery % Zn | 80.7 | 80.6 |
| Reagent Consumption (g/t) | | |
| Cu Rougher Float | 17 | 24 |
| Zn Rougher Float | 0* | 10 |

* With AEROPHINE 3418A promoter being fed on the Cu rougher float, no additional collector was required in the Zn float.

CASE II – Improved Silver Metallurgy

A ten-month test was undertaken at a 4,000 tonnes per day copper-zinc-silver mine. Metallurgy obtained with standard promoter, potassium amyl xanthate (PAX), was compared to the performance of a mixture of AEROPHINE 3418A promoter and PAX.

Figure 1 shows composite monthly silver tailings assays as a function of head grades for nine months of the ten-month test.

Although the data is scattered, it is apparent that there is a trend to lower silver tails assays with the AEROPHINE 3418A / PAX combination.

The average metallurgy over the ten-month period is summarized in Table 2. The use of AEROPHINE 3418A promoter resulted in a 6% increase in silver recovery. Small but significant improvements in copper metallurgy were also observed together with a small reduction of zinc reporting to the copper concentrate.

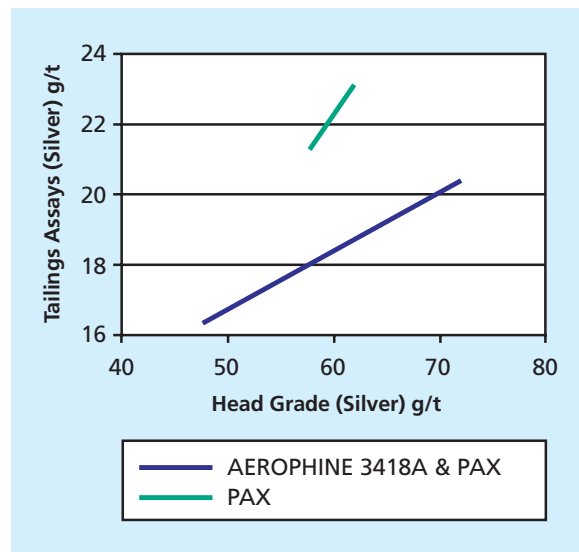
Table 2. Case 2: Improved Silver Metallurgy

| Parameters | AEROPHINE 3418A + PAX | PAX |
|----------------------------------|-----------------------|------|
| Heads % Cu | 1.82 | 1.69 |
| Ag(g/t) | 56.6 | 55.4 |
| Cu Conc. % Cu | 27.6 | 27.6 |
| Cu Tails % Cu | 0.13 | 0.16 |
| Cu Recovery % | 92.9 | 90.5 |
| Con. %Zn | 4.9 | 5.1 |
| Cu Tails – Ag (g/t) | 18.3 | 20.2 |
| Ag Recovery % | 67.6 | 61.5 |
| Reagent Consumption (g/t) | | |
| AEROPHINE 3418A | 27 | 0 |
| PAX | 12 | 39 |

Summary

AEROPHINE 3418A promoter is able to provide a unique combination of strength and selectivity within a flotation cell. The two case studies presented are examples of the many applications where its use has resulted in improved performance. Not only are the benefits seen in Cu or Zn recovery but also precious metals, providing significant potential improvements to operations.

Figure 1 – Increased Silver Recovery



Cytec is reinforcing our commitment to the mining industry by expanding our global team. Our most recent group of new employees brings a depth of industry experience and technical knowledge to our organization.

Héctor Yáñez has joined Cytec as the SX Technical Manager for the LA region. Héctor has more than 20 years of experience in copper hydrometallurgy and worked previously in mining operations at Quebrada Blanca, Radomiro Tomic and Minera Pudahuel.

Alexis Soto has joined Cytec's as ATG (Applications Technology Group) as a Technical Specialist. Alexis has thirteen years of experience in copper hydrometallurgy and worked previously in the company CIMM, giving technical support to the hydrometallurgical operations in Chuquicamata and Radomiro Tomic. Most of his previous work was related to R&D projects.

Edgar Ricce joined Cytec MEP family in April 23, 2007. Edgar is located in Lima and his primary responsibility is to support Cytec - MEP business in Perú, reporting to the LAG Regional Sales Director for MEP. Edgar graduated with a degree in Chemical Operations and Metallurgy from Tecsup in Lima, Peru. He is currently continuing studies in Engineering Economics at Universidad Científica del Sur. Edgar had fourteen years of experience in hydrometallurgical mining operations, including Grupo Mexico's Toquepala plant and Xstrata's Tintaya plant. His last position was Leach-SX-EW operations supervisor at Tintaya. Edgar is also a Six Sigma Green Belt. Cytec welcomes Edgar, his wife Jessica and sons Oscar and Sergio to the Cytec family.

Kola Koiki has joined Cytec's Metal Extraction team in Phoenix, AZ as Senior Technical Specialist. Kola joins Cytec from Huntsman Polyurethane Chemicals where he was responsible for technical service and sales. He also has experience from IPI International and National Starch and Chemical Company. Kola has a degree in Chemistry from Moscow University and also a Master degree in Chemical Engineering from Moscow Chemical Engineering Institute. We want to welcome Kola, his wife Suzette, and five children to the Cytec Mining Chemicals family.

Enrique Villegas joined Cytec's Metal Extraction team in Phoenix, AZ as Technical Specialist. Enrique joins Cytec from Grupo Mexico where he served as a supervisor in both hydrometallurgy and pyrometallurgy areas. Enrique Villegas also has experience from Panamerican Silver where he worked looking on how to improve cyaniding of precious metals. Enrique Villegas has a degree in Metallurgy from San Luis Potosi University and is currently working out of Hermosillo, Sonora, Mexico.

Tyler McCallum has joined Cytec's Metal Extraction team in Phoenix, AZ as a Laboratory Technician. Tyler started with Cytec as a student intern in June, 2006 and started learning and gaining experience in solvent extraction through his internship. Tyler has a degree in plant biochemistry from Arizona State University. He gained experience in organic chemistry and biochemistry through his studies at the University.

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|--|------------|-----------|---|---|
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| TMS 2008 - Booth 731 | 3-9-2008 | 3-13-2008 | Ernest Morial Convention Center | New Orleans, Louisiana |
| ExpoMin 2008 | 4-15-2008 | 4-18-2008 | Venue Espacio Riesco | Santiago, Chile |
| ALTA 2008 Nickel-Cobalt, Copper & Uranium Conference | 6-16-2008 | 6-21-2008 | Sheraton Hotel Perth | Perth, Western Australia |
| Hydrometallurgy 2008 | 8-17-2008 | 8-20-2008 | JW Marriott Desert Ridge Resort | Phoenix, Arizona |
| Alumina Quality Workshop 2008 (AQW) | 9-7-2008 | 9-12-2008 | Darwin Convention and Expo Center | Darwin, Northern Territories, Australia |
| ISEC (International Solvent Extraction Conference) 2008 | 9-15-2008 | 9-18-2008 | Hotel Arizona | Tucson, Arizona |
| IMPC 24th (XXIV International Mineral Processing Congress) | 9-24-2008 | 9-28-2008 | Beijing International Convention Center | Beijing, China |



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Contact Us

Corporate Headquarters

Cytec Industries Inc.
Five Garret Mountain Plaza
West Paterson, NJ 07424 USA
Tel: +1 973 357-3193
US Toll Free: +1 800 652-6013
Fax: +1 973 357-3117

South American Regional Office

Avda. Andrés Bello 2687
Torre Pacifico, Piso 23
Las Condes, Santiago, Chile
Tel: +56 2-560-7927
Fax: +56 2-560-7902

Europe, Africa and the Middle East Regional Office

Cytec Industries BV
38, Franko Str., Of. 4
Kiev, 01030
Ukraine
Tel: +380-44-2302093
Fax: +380-44-2386076

North American Regional Office

Cytec Industries Inc.
2085 E. Technology Circle
Suite 102
Tempe, AZ 85284 USA
Tel: +1 480 730-2000
Fax: +1 480 730-2245

Asia Pacific Regional Office

Cytec Australia Holdings Pty Ltd.
Suite 1, Level 1, Norwest Quay
21 Solent Circuit
Baulkham Hills, NSW 2153
AUSTRALIA
Tel: +61 2-9846-6200
Fax: +61 2-9659-9776

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Please direct any questions, comments, or requests for corrections or changes to the distribution list to Sherry Sutton:
Phone (U.S.) +1 973-357-3276
email: Sherry.Sutton@Cytec.com

www.cytec.com