The Intec Copper Process: development of a new electrowinning cell

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ABSTRACT

The Intec Copper Process is based on the electrolytic deposition at the cathode of LME Grade A copper, in dendritic form, from a purified sodium chloride-sodium bromide electrolyte. During electrowinning (EW), the mixed halide species $BrCl_2^-$ ("Halex^{TM}") is generated in solution at the anode and exhibits powerful leaching characteristics when re-circulated to treat the sulfide concentrate feed. Since completion in 1999, of a one tonne Cu per day demonstration plant program at St. Peters in Sydney, a new and much improved electrowinning cell of conventional configuration has been designed and patented, with a demonstration unit of the improved cell continuously operated at Intec's laboratories at the University of Sydney. As part of this program, copper dendrites produced at commercial scale will be melted and cast into oxygen-free 8 mm copper wirerod in a pilot plant owned by Rautomead International Ltd. of Dundee, Scotland. This paper describes the development of the new EW cell design for the continuous production of dendritic copper. The project was divided into three phases covering basic design at laboratory scale, prototype testing at full scale and demonstration of the refined prototype in a commercial EW cell with a 25% electrode complement. Phases I and II have been completed while Phase III will not commence till funding is in place.

INTRODUCTION

The Intec Copper Process is a proven, patented hydrometallurgical process for the extraction of pure copper and precious metals from sulfide concentrates. The process is based on the electrolytic deposition at the cathode of LME (London Metal Exchange) Grade A copper in dendritic form from a purified sodium chloride-sodium bromide electrolyte. During electrowinning (EW), the mixed halide species $BrCl_2^-$ ("Halex^{TM}") is generated in solution at the anode, and it exhibits powerful leaching characteristics when it is re-circulated to treat the sulfide concentrate feed. The use of a mixed-halide lixiviant makes the Intec Copper Process unique among the range of hydrometallurgical and bio-hydrometallurgial alternatives to conventional smelting technology for the production of copper from copper sulfide concentrates.

Since completion in 1999 of a one tonne Cu per day demonstration plant program at St Peters in Sydney, a new and much improved electrowinning cell of conventional configuration has been designed and patented, with a demonstration unit of the improved cell continuously operated at Intec's laboratories at the University of Sydney. As part of this program, copper dendrites produced at commercial scale will be melted and cast into oxygen-free 8 mm copper wirerod in a pilot plant owned by Rautomead International Ltd of Dundee, Scotland.

This paper describes the development of the new EW cell design for the continuous production of dendritic copper. The project was divided into three phases covering basic design at laboratory scale, prototype testing at full scale and demonstration of the refined prototype in a commercial EW cell with a 25% electrode complement. Phases I and II have been completed, but Phase III will not commence till funding is in place.

A single EW cell, producing one tonne of copper per day, was included in Intec's demonstration plant, located in Sydney and which operated over a twelve-month period during 1998/99. The cell produced approximately 180 tonnes of saleable copper over this period, but exhibited several problems with the cathode and product recovery system employed. The aim of the current project has been to develop an EW cell of optimal design to electrowin dendritic copper from chloride-based leach solutions for use in a commercial-scale plant.

Intec Copper Process Description

The patented Intec Copper Process was developed for the recovery of copper at LME Grade A from sulfide concentrates and has been described in detail in a number of earlier papers (1, 2). In overview, the Intec Copper Process consists of the three sequential circuits of leaching, purification and EW, as shown in the simplified flow diagram in Figure 1. The leach section is of a three-stage counter-current configuration. Purification consists of cupric reduction, silver recovery, pH 4 impurity precipitation and finally pH 9 impurity precipitation on a bleed from the EW circuit. The EW circuit consists of the recovery of copper metal and the simultaneous regeneration of the leach liquor.

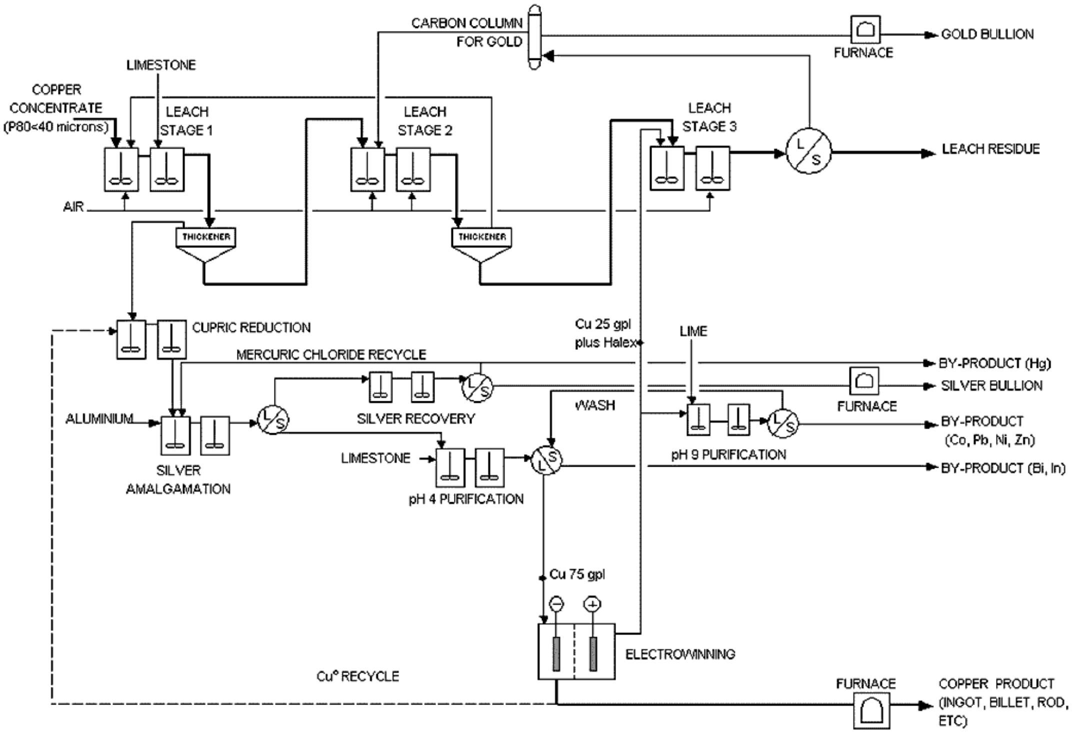

Figure 1 - Intec Copper Process Flow Diagram

EW Fundamentals

The heart of the Intec Copper Process is the EW cell. Copper metal is electrowon from a purified electrolyte, which has a composition of 80 g/l copper (as cuprous ion, Cu^+), 250 g/l sodium chloride (NaCl), 30 g/l calcium chloride ($CaCl_2$) and 30 g/l sodium bromide (NaBr). By passage of electric current at 1000 A/m^2 of superficial electrode area, high purity copper dendrites are formed on the cathode. The feed electrolyte copper tenor is depleted to 27 g/l (still in the monovalent form), which is the steady state concentration of the cell.

The depleted or spent electrolyte continuously permeates through a filter cloth membrane to the positively charged anode where the residual copper is oxidised to the divalent cupric form (Cu^{++}). Under normal circumstance, with 53 g/l of the feed copper stripped at the cathode and with only 27 g/l available for oxidation at the anode, there would be generation of chlorine gas to the extent necessary to balance the electron equation. However, because of the presence of both chloride (Cl^-) and bromide (Br^-) in solution, there is the preferential formation of the halogen species $BrCl_2^-$, given the generic name of "Halex™", which can be viewed as a chlorine molecule bonded to a bromide ion, which renders it soluble. This electrolyte is now a very powerful lixiviant at an oxidising potential (Eh) of 1000 mV [Note that chlorine gas does not form below an Eh of 1100 mV] and is used for the leaching of copper sulfide concentrates.

PROJECT DESCRIPTION AND OBJECTIVES

The project was divided into three phases as described below:

- *Phase I*
  Laboratory study to select the most suitable cathode and wiping design and to test the suitability of a new anode design.

- *Phase II*
  Scale up of the laboratory designs to a commercial size prototype for demonstration of a single electrode pair producing 7kg/hr of copper. During the program, two tonnes of copper dendrites were recovered to demonstrate the direct conversion to 8mm diameter oxygen-free copper wirerod.

- *Phase III*
  Expansion of the prototype to eight electrode pairs representing 25% of the capacity of a full-size commercial cell. During the program, commercial quantities of wirerod will be produced for the purposes of commercial acceptance testing.

Phase I - Laboratory Study

The laboratory study was conducted to choose the most suitable design and construction materials for the anode, cathode and wiper using a 10 litre transparent cell.

Anode

The anode installed in the 1998 demonstration plant EW cell was of a flat plate design. This performed satisfactorily throughout the life of the project; however a box design utilising titanium mesh would have the advantage of allowing better electrolyte flow inside the anode chamber and less ohmic drop due to the shorter path between the active anode surface and the cathode.

The laboratory-scale anode, as shown in Figure 2, was constructed with a centrally located conductor bar of titanium-clad copper to match the proposed commercial anode. The entire structure was activated with a coating of Ru/Ir oxides and enclosed in a filter cloth membrane bag. Results obtained after 200 hours of testing showed that it is a sound alternative to the titanium plate anode used in the demonstration plant.

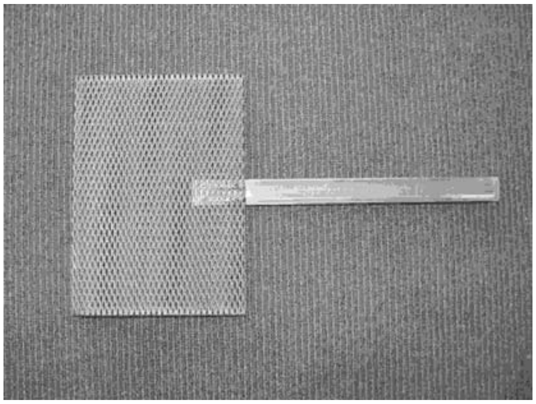

Figure 2 – Laboratory-Scale Titanium Mesh Anode

Cathode

A one-piece titanium cathode with a corrugated profile was developed after intensive testing of various designs, which included, plate, mesh, rod and ladder configurations. The corrugated design, as shown in Figure 3, has a 60 degree included valley angle that had desirable dendritic growth characteristics. The chosen cathode design is beneficial because there is no indication of copper skin formation around the valley bottoms of the corrugations, as demonstrated in Figure 4. Any tendency for the electrowon copper to lock together the deposits on both sides of the valleys is undesirable from a wiping perspective.

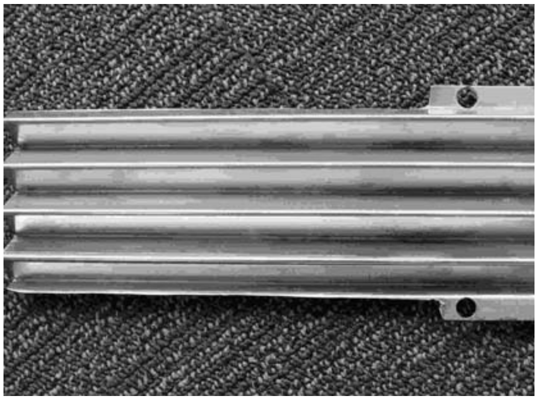

Figure 3 – Laboratory-Scale Corrugated Titanium Cathode

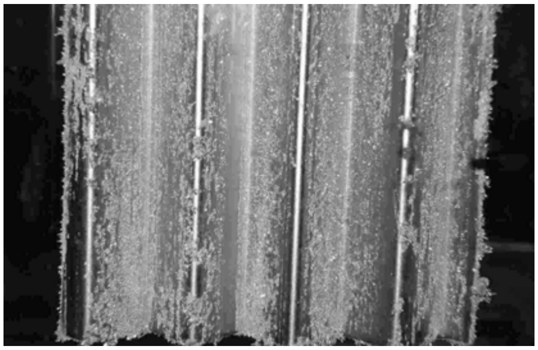

Figure 4 - Beaker-scale Copper Deposition Showing Clean Valley Bottoms

Deeper corrugations at the 60 degree angle were found to grow copper around the valley bottom and to produce a different morphology. Opening the corrugations to give a greater valley angle was found to plate copper all over the surface. Tighter valley angles than 60 degrees could not be tested due to difficulty with folding the material.

Optimum current density for best copper morphology was tested with a flat cathode. It was found that a value in the region of 500amps/m^2 gave the best results and this density is applied to the expanded surface area of the corrugated cathode, which is twice the cathode projected area. By comparison, the Duval CLEAR process produced copper on a dimpled cathode that operated at 1,800amps/m^2. The resulting copper was amorphous and non-adherent, but there was difficulty in starting the cells due to hydrogen formation and the formation of floating copper particles.

The test results from the laboratory-scale cathode showed that the corrugated design had several advantages over the other designs considered; and these advantages include the following:

- A sufficiently high surface area and consequently a sufficiently low current density to ensure crystalline dendritic growth starting from a clean surface. This is a very important requirement for any cathode design, as regular removal of all copper growth is essential to ensure that the growth does not become coherent, which can lead to a plate of inter-growing dendrites that cannot be harvested. As current density increases, growth tends towards finer crystal size that increases the risk of co-deposition of impurity metals.
- Good stiffness by virtue of its corrugated profile.
- Ease of construction, which results in a relatively low cost, and
- A projected long life, since construction is exclusively from titanium.

Permutations on this corrugated design have been patented by Intec to give wide intellectual property coverage.

Wiper

The principal characteristic of the EW process in a halide environment is that copper is deposited in the form of dendrites [4], which introduces the potential for continuous production. This however requires a mechanism (wiper) combined with the cathode to provide for continuous copper harvesting. The wiper is designed to match the cathode profile such that a minimal gap exists between the two, avoiding direct contact but forming a tight wiping action. Wipers constructed from titanium and ceramics were tested at the laboratory stage, both acting by wiping in a scraping mode down the cathode, with the wiper blades or teeth trailing behind their fixing point at an angle of 30 degrees to the vertical, effectively removing deposits with a wedge of material ahead of the wiper. The actuating mechanism is designed to open the wiper teeth to the vertical position before returning to the top of the cathode ready for the next cycle.

The titanium wiper and the actuating mechanism are shown in Figure 5, but the wiper blade was found to suffer from the electro-deposition of copper onto the blade. Coating the blade with ceramic was considered but rejected as unnecessarily complicated.

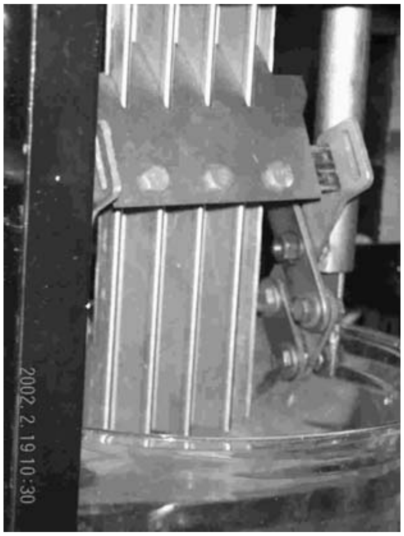

Figure 5 - Experimental Titanium Wiper Blade

The ceramic wiper design as shown in Figure 6 gave the best results with no significant accumulation of copper dendrites on the cathode over a 50-hour period. Consequently, this design was transferred to the prototype cell. Individual ceramic teeth were mounted between two titanium bars and held with pegs located in half-circular notches in the teeth.

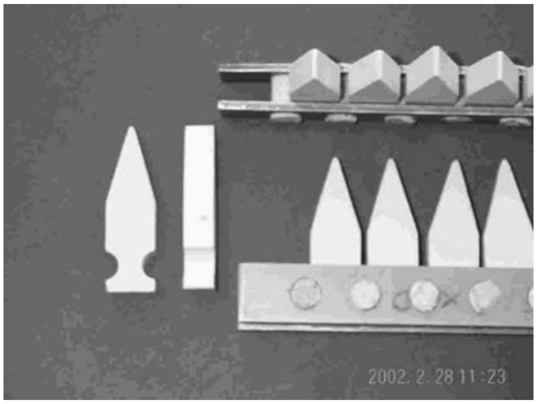

Figure 6 - Experimental Ceramic Wiper

Phase II - Cell Prototype Study

Design Basis

Table I presents the design parameters for the cell prototype and the predicted operating performance.

Table I – Design Parameters for the EW Cell Prototype*

Parameter	Design value
Feed copper tenor (g/l)	80
Cell copper tenor (g/l)	27
Cathode number	1
Anode number	2
Current density (A/m^2)	1000
Cell potential (V)	3.2
Cell efficiency (%)	96
Daily production (kg)	178
Temperature (°C)	75

Description of Process

A simple block flow diagram of the EW cell test circuit is presented in Figure 7, with the two unit operations of electrowinning and cupric reduction highlighted.

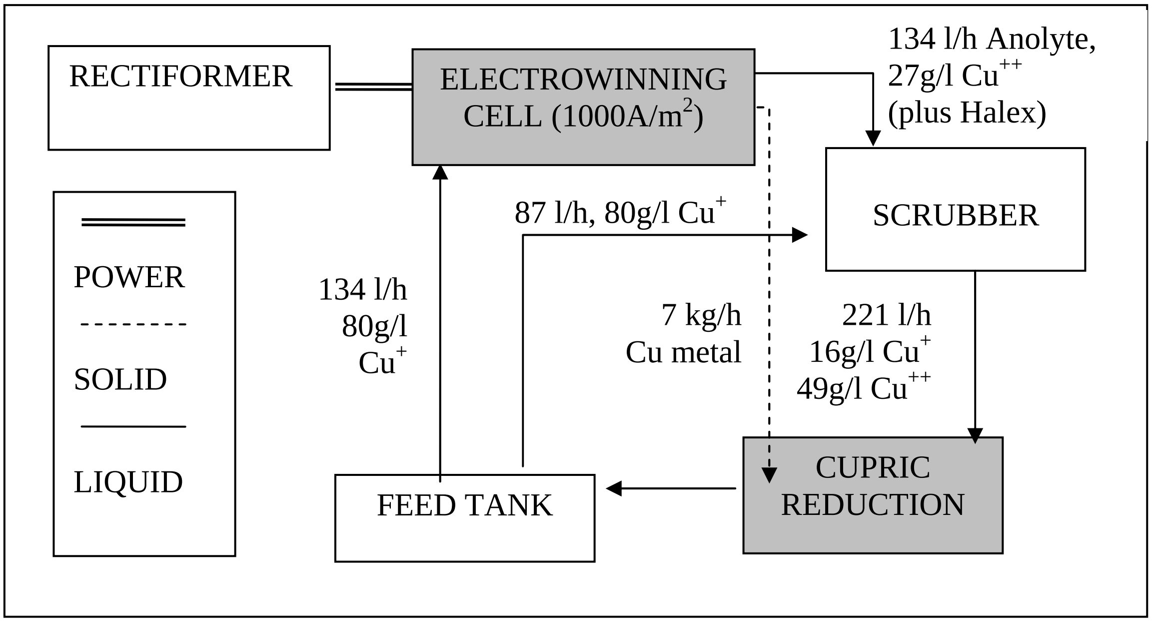

Figure 7 – Electrowinning Cell Test Facility Block Flow Diagram

The rectifier current to the electrodes is based on the active shadow area of the cathode (1.57 m^2 per face) and the prescribed current density of 1000A/m^2, which equates to 3140 A. The temperature in the cell was controlled at 75°C with 4 titanium immersion heaters. The electrolyte resistivity decreases with temperature up to 70°C, above which point it essentially remains constant.

Product copper dendrite from the cell is re-dissolved in spent electrolyte in order to synthesise fresh electrolyte.

Cell Configuration

Table II outlines the differences between the demonstration plant cell and the new cell design, with a description of each component.

Table II – New Cell Design Features

Cell sub-system	Demonstration plant Cell Design	New Cell Design
Current Density	500 A/m^2	1000 A/m^2
Current per Cell	25000 amps	100000 amps
Current Efficiency	96%	96%
Cell Potential	2.4 V	3.2 V
Cell Power Consumption	1050 kWh/t Cu	1400 kWh/t Cu
Tank	4m tall x 3m diameter circular FRP (hopper like) tank with off-centre bottom (22m^3 at 475tpa of Cu)	2m tall x 2m wide x 6m long rectangular polymer concrete tank (22 m^3 at 1900tpa of Cu)
Cathode	Polyurethane-coated titanium spot (dimple) – 16 units, 1.25m H x 1.25m L (4000 spots/face)	Corrugated titanium without coating – 32 units, 1.0m H x 1.57m L (77 ridges/face)
Wiper	Insulated titanium wire, lateral wiping motion	Retractable ceramic teeth, vertical wiping motion
Anode	Rare earth metal oxide coated titanium plate with titanium clad copper bars	Rare earth metal oxide coated titanium mesh box with titanium clad copper bars
Anode Chamber	Fibreglass frame with filter cloth attached	Filter cloth bag supported by anode
Product Removal	Bottom retrieval as slurry via pump with settling column	Ribbed conveyor belt with inclined top exit

Cell Design

The electrode orientation is longitudinal relative to the cell, as shown in Figure 8, in order that the cell and product conveyor can be minimised in size. The cell is of standard industrial copper tankhouse design in polymer concrete, with modifications for the conveyor ramp and additional freeboard with dimensions of (L)4.2 m x (W)1.1 m x (H)2.0 m. The cell is well able to continuously withstand the operating temperature of 75^{0}C and the chemical impact of the process liquor.

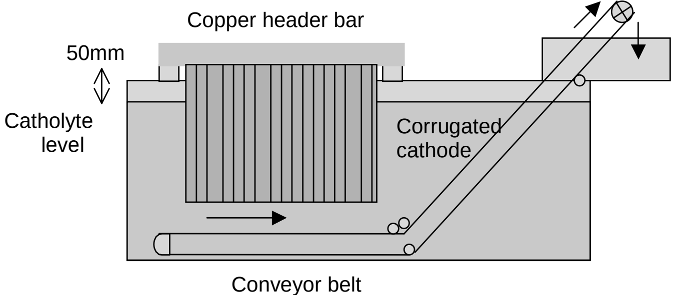

Figure 8 - Schematic Longitudinal Cross-section of the Prototype EW Cell

Electrolyte Circulation

A uniform electrolyte composition is desired to ensure a constant copper tenor over the cathode face. This is targeted in the prototype cell by recirculating electrolyte around the cell and adding new cuprous solution to the pumped circuit so that an even electrolyte composition is produced. Electrolyte is distributed within the prototype cell by two distribution headers, one each side of the cathode, on the longitudinal axis. Six holes are drilled in each header to distribute the electrolyte evenly along the cathode. The cell level is maintained by overflowing a volume equivalent to the make-up liquid feed through the two anode compartments.

Cathode

The cathode was designed with 77 ridges, 20 mm apart with overall dimensions of (W)1540 mm x (H)1126 mm. Current is supplied through a 76 mm x 25 mm titanium-clad copper header bar that is continuous-welded directly to the cathode panel as shown in Figure 9.

Figure 9 – Prototype Cathode

Anodes

Each anode is constructed from 2 panels of 1 mm thick titanium expanded mesh to form a box with an overall dimension of 1000 x 770 x 12.5 mm. Three 25 mm x 12.5 mm titanium-clad copper bars are welded into the structure to distribute the current and locate the mesh panels. Two anodes are placed adjacent to each other and enveloped in a bag manufactured from a woven polypropylene filter cloth with a PVDF pipe attached at the top for anolyte discharge. The six current distribution bars are bolted to two 150 mm x 6.25 mm copper header bars. The anolyte discharge ports are connected to a manifold passing through the cell tank wall to allow gravity discharge.

Anode/Cathode Gap

A gap of 60 mm was initially allowed between anode and cathode faces to provide space for dendrite growth and wiper access. Electrolyte potential-drop has previously been measured at 11mv per linear mm of gap at 75^0C and 1,000A/m^2 current density, resulting in electrolyte potential drop of 0.66 V in an anticipated overall cell voltage across the busbars of 3.37 V. The minimum practical anode/cathode gap is 45 mm, both from the consideration of fitting a wiper between the anode and cathode, and from consideration of permitting a reasonable dendritic growth, without electrical shorting, before wiping. The best overall voltage across the busbars is therefore anticipated to be around 3.20 V.

Wiping Mechanism

The wiper bar in the prototype cell differs from the laboratory-scale cell by being notched at the front for the ceramic teeth with a hole drilled in the rear portion for the insertion of a titanium reinforcing bar. A second set of teeth was manufactured from ultra high molecular weight polyethylene (UHMWPE) to act as a back-up. The teeth holder was manufactured from polypropylene.

Actuation of the wiper bar between the vertical or open position and the closed position, as previously described, is via two pneumatic cylinders acting through a bell crank. The wiper bars are mounted on a titanium sub-frame that remains submerged below the catholyte surface with vertical links at each corner connecting to a second sub-frame of painted steel that sits above the electrode assembly. Actuation of the wiper assembly is via four screw jacks driven from a common gear-drive and located at the corners of the sub-frame. The sub-frame is mounted on load cells, to make an estimate of the force exerted by wiping on the down stroke compared with the return stroke. The load measurement is not an eventual feature of the commercial plant, but was considered necessary to specify Phase 3 equipment design.

Sequencing of the wiper, as well as all other plant operations, was via an ABB Industrial^{IT} Open Control System, a digital control system (DCS), utilising various hardware and software applications for communication between the man-machine interface (MMI) and the controller. The small system utilised one process controller and nine I/O racks catering for:

- 32 analog inputs
- 8 analog outputs
- 32 digital inputs
- 16 digital outputs.

Cell Conveyor

The cell conveyor plays a key role in the overall success of the electrowinning cell. The conveyor must be totally resistant to the effects of immersion in the process liquor and must be totally reliable for long operating periods of years to avoid the need to dismantle the cell to gain access. The conveyor system is located in the bottom of the cell and consists of a continuous belt fabricated from rubber that is 500mm wide with rippled side edging to prevent copper from falling off the belt and horizontal ribs to provide resistance to dendrites sliding backwards on the exit ramp. Several rollers constructed from UHMWPE ensure accurate tracking of the belt. Inclined polypropylene baffles were also used to ensure that copper from the cathode was directed onto the belt. The conveyor system was designed and constructed by Delkor Pty Ltd. A picture of the conveyor prior to installation in the prototype cell is shown in Figure 10.

Figure 10 - Cell Conveyor

Plant Area

The cell prototype test program was conducted in the Chemical Engineering Department of the University of Sydney. Construction of the test facility commenced in mid November 2003 and was finalised in early February 2003. Figure 11 presents a picture of the EW cell and wiper superstructure.

Phase III – Expanded Prototype Cell

Phase III of the project will not commence till funding is in place.

Figure 11 – Cell and Wiper Superstructure

RESULTS

Test Run Number One

Commissioning was incorporated into test run number one and was conducted on a semi-continuous basis during February 2003 with 293 hours of operation.

Wiper Mechanism

During this period, it became apparent that the wiper bar was not sufficiently stiff to maintain the desired tolerance between the wiper teeth and the cathode resulting in the build-up of a permanent layer of dendrites over time.

In spite of the wiper problems, the polymer concrete cell did not cause any difficulties and the conveyor worked without fault. Figure 12 shows copper dendrite recovery from the EWC via the conveyor belt system. Performance of the titanium mesh anodes was also satisfactory.

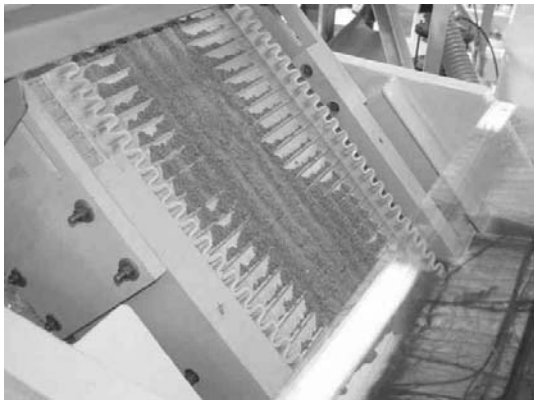

Figure 12 – Copper Dendrite Recovery from the EW Cell via Conveyor

Design Improvements

The poor performance of the wiper was attributed to insufficient stiffness of the wiper bar and relatively poor alignment of the wiper teeth with the cathode ridges and valleys. This was addressed by a redesign of the wiper bar and teeth by a consultant mechanical engineer, leading to the following basic design changes:

- Trapezoidal-section Hastelloy beams of section 32 mm by 40 mm, coated in a plastic skin for electrical insulation, were added to support and stiffen the two wiper bars that were increased in diameter from 19 mm to 26 mm
- New Individual wiper teeth were custom fitted on the wiper shaft to suit the profile of the cathode corrugations.

Individual wiper teeth, as shown in Figure 13, were slotted onto the solid titanium round bar with every third tooth drilled and pinned into the titanium bar at the correct angle for best-fit with the cathode. Teeth are tensioned together by a secondary small diameter titanium rod passing through a matching drilling in all the teeth. Tooth construction material has been changed from the ceramic used initially to Ertalyte, a semi-crystalline thermoplastic polyester (PETP). Ertalyte's properties make it especially suitable for the manufacture of precision mechanical parts capable of sustaining high loads in challenging wear conditions, and it is strong at the cell operating temperature of 75^0C.

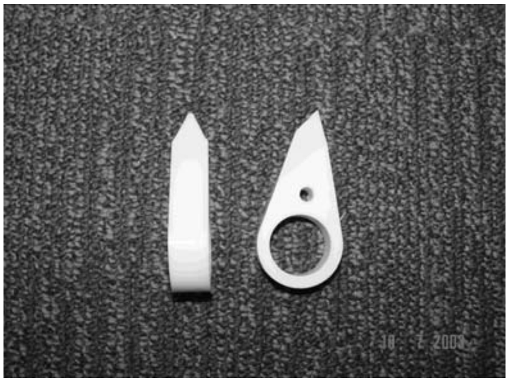

Figure 13 - Wiper Teeth Design for Revised Wiper Bar

The new wiper structure comprising the wiper bar and trapezoidal support beam has the capability to deliver 400 kgf before deflecting.

Test Run Number Two

Test run number two verified the new wiper, producing 3500 kg of copper dendrites over 21 power-on days of operation.

Wiper Mechanism

After an extended period of stable EW cell operation, the current was turned off and the cathode was raised in order to check dendrite morphology and coverage immediately prior to a closed wiping cycle. Dendrite quality at this time was observed to be excellent, with no bridging from ridge to ridge, nor any copper deposition in the valleys. Figure 14 shows a close-up of the unwiped cathode raised above the cell. It should be noted that the cathode is not normally raised as it is wiped below the surface of the electrolyte.

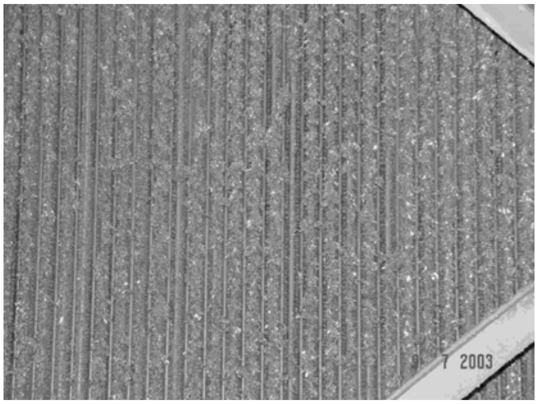

Figure 14 - Un-wiped Cathode in Raised Position

The cathode was again lifted immediately after a closed wipe to inspect for residual copper dendrites. Figure 15 shows a close-up of the wiped cathode with essentially complete dendrite removal. The small number of residual dendrites are removed during the next closed wiping operation. Repeat inspections of the cathode have confirmed that there is no formation of a residual base-coating of dendrites, as was experienced during run number one.

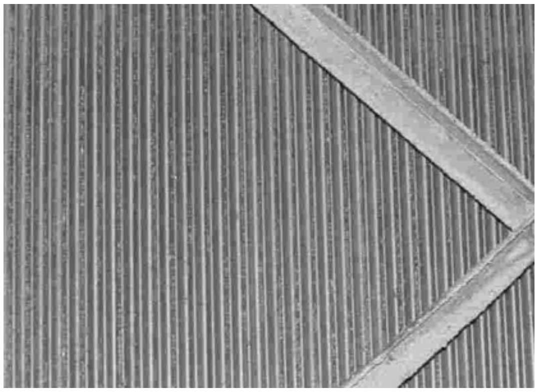

Figure 15 – Wiped Cathode in Raised Position

The consultant mechanical engineer considers the stiffness of the modified wiper assembly to be excessive for the easily harvested dendrites witnessed during run number two. It is considered that the trapezoidal support beam can be thinned down for 200 kgf capability or even removed completely by relying on the stiffness of the wiper bar. These optimisation issues will need to be addressed during the Phase III program.

Alternative Wiper Design

Present wiper design assumes a full-width wiper on both sides of each cathode in a cell equipped with 32 cathodes. The current design is not complex, however, any reduction in the number of mechanical components would reduce cost and the risk of malfunction.

An alternative to the fixed wiper design for each cathode is an indexing system that wipes each cathode in sequence with a single moving wiper assembly, servicing each cathode sequentially. The advantages of this approach would be a reduction in the number of moving parts and easy substitution of a wiping assembly in the event of malfunction. An assessment of the alternatives will be made at the time of proceeding to Phase 3 with a quarter-length anode/cathode pack of eight electrode pairs. The consultant mechanical engineer believes an indexing system would be relatively easy to design resulting in significant reductions in moving equipment and cell complexity. An indexing system offers the potential to remove complexity, components and cost, and provide an accessible mechanism for easy maintenance.

Cell Potential

Cell potential is determined by the electrochemical potential and ohmic losses through the electrolyte and connective metals. Electrolyte losses are determined by solution resistivity and width of the anode/cathode gap, hence the need to employ the narrowest of gap possible subject to robust wiper performance and avoidance of whisker formation that grows to the anode and shorts the circuit. Shorting is a major problem in conventional copper electrorefining tankhouses with much manual short clearance being necessary to prevent inefficient current consumption. The Intec cell wiper design eliminates this manual work above the cell.

The wiping sequence employed during run number one and for most of run number two was based on a closed wipe once per hour and an open wipe 30 minutes into the sequence. This sequence is given the code COC30. Figure 16 shows the cell potential profile generated by this sequence over a 27-hour period with potential rising and falling at each wipe cycle within the range 3.21-3.46 V with an average of 3.33 V. The intermediate wipe with an open wiper head is seen to produce a smaller potential rise than the hourly closed wipe when effectively all the dendrite is removed from the cathode. In a tankhouse with multiple cells operating concurrently, the potential fluctuation will be minimal.

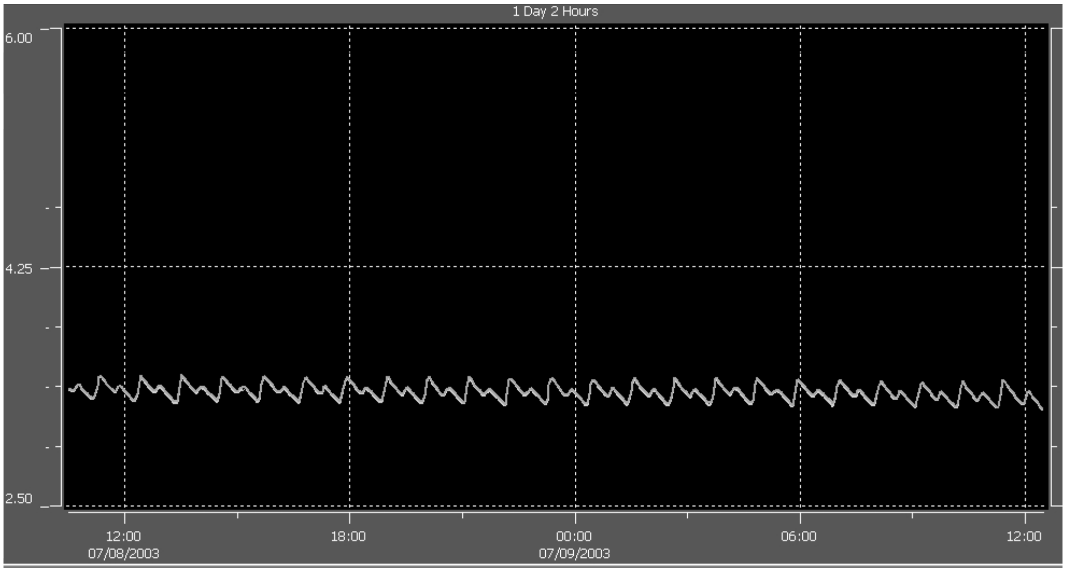

Figure 16 – Cell Potential under Wiping Sequence COC30

Sequence optimisation resulted in the extension of the closed-wipe frequency from 1 hour to 1.5 hours with 2 closed wipes at 30 minute intervals (code COOC30), generating the voltage profile shown in Figure 17 over a 12-hour period. The potential range was 3.16 – 3.44 V, averaging 3.28 V.

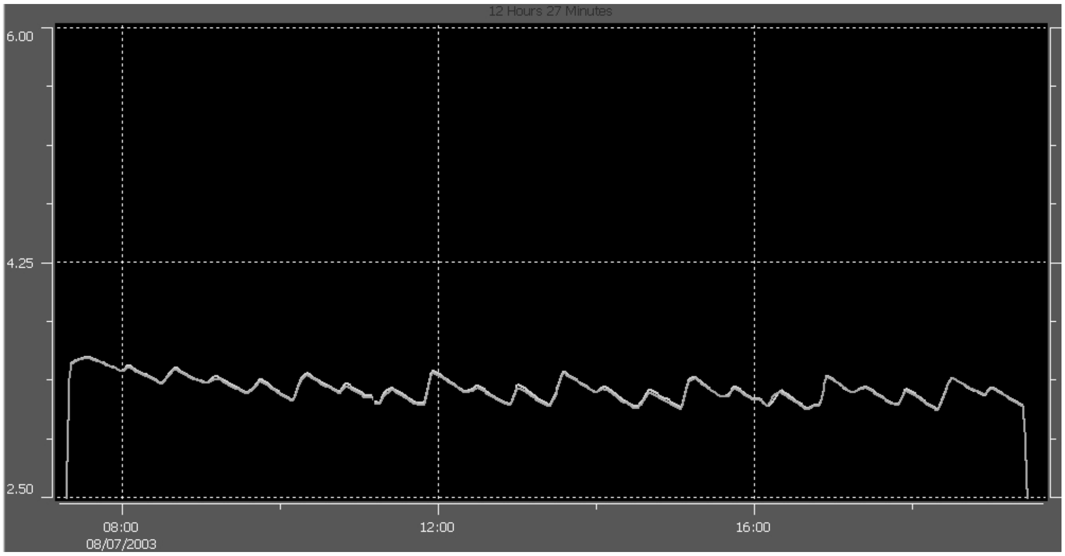

Figure 17 – Cell Potential under Wiping Sequence COOC30

The optimum sequence appears to be a closed-wipe frequency of 2.25 hours with 2 x 45 minute open wipes (code COOC45) for a potential range of 3.10 – 3.41 V, averaging 3.24 V with the profile shown in Figure 18.

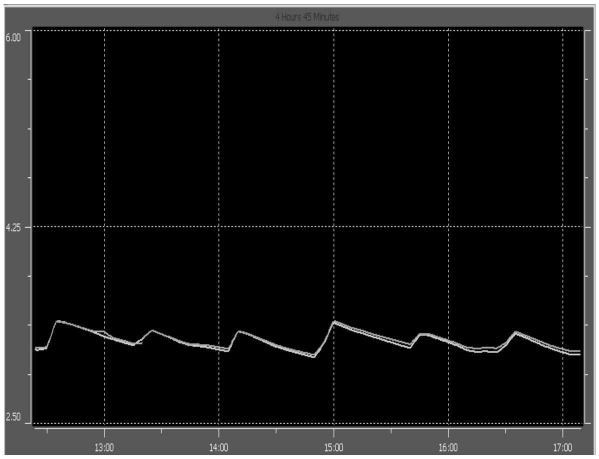

Figure 18 – Cell Potential under Wiping Sequence COOC45

Electrical Current Efficiency and Energy Consumption

The major operating comparator for metal tankhouse operation are the efficiency of use of electrical current measured against theoretical requirements from Faraday's Law, and the energy used to produce a unit of product copper. The latter is a function of the overall voltage from cathode-to-anode header bars to make the index comparable between sites and technologies. Transformation losses in the transformer/rectifiers and distribution losses in the bus-bars are site-dependent.

Current efficiency is affected by the cuprous/cupric ration in feed, which in the prototype cell is determined by the reaction of copper with cupric anolyte. It is also affected by oxidation of cuprous solution at the surface of the electrolyte to form copper oxychloride and back-mixing of the anolyte by hydraulic exchange. A 100% current efficient cell would deposit 2.37 kg of copper per hour for a current flow of 1,000 A. Any less deposition is a measure of the cell inefficiency. During the second test run, careful collection of copper dendrites produced over a 12-hour period gave an indicated current efficiency of 96%. The energy consumption was calculated for the prototype cell, while operating under the wiping sequence COOC45, resulting in a value of 1425 kWh per tonne of dry product dendrite. This figure refers to the energy across the anode and cathode header bars but does not include losses in the bus-bars and transformer/rectifiers.

Washing and Drying

A combined batch washer/dryer was built to generate 2,000 kg of dry dendrite for trial briquetting prior to upcast rod drawing at the headquarters of Rautomead International Ltd. in Dundee, Scotland. Dendrites as produced by the process have good washing and drying characteristics.

Batches of dendrites equivalent to 3 hours production (25 kg) are processed in an inclined drum with an inert atmosphere (nitrogen) to prevent excessive oxidation. Solution drains through a perforated plate in the drum base and a sequence of acidified water washes followed by deionised water are added through the drum lid. There are sufficient displacement washes to produce essentially chloride-free dendrite (typically less than 1 ppm chloride). Clean dendrites are blown with nitrogen to displace excess water and dried by heaters surrounding the drum of the dryer and in the lifter bars within the dendrite bed to 120^0C at the end point.

Downstream Processing

Initial quantities of washed and dried dendrites have been provided to the Australian agent of the German compaction company RUF, in Eden, NSW, for the production of ram-pressed briquettes of 50mm diameter with lengths from 50 mm to 75 mm (shown on Figure 19) in the RB15 two-stage press. Briquette densities ranging from 92% to 95% of true density were produced.

It is not intended that a ram press should appear in the final commercial flowsheet, but it is a convenient way to handle and transport material for evaluation, such as the material being sent to Rautomead in Scotland for rod casting. Eventual production flowsheets will most probably be based on induction melting of washed and dried dendrites, followed by laundered feed to a rod, or other, casting machine.

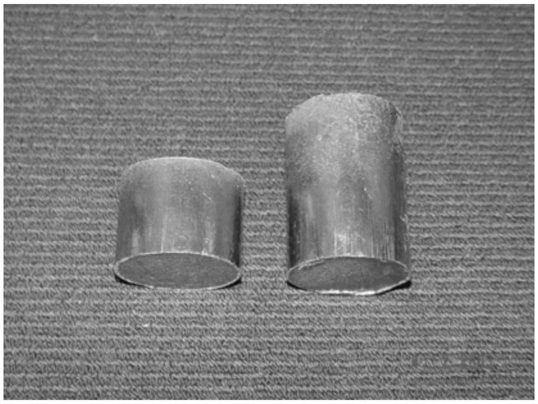

Figure 19 - Two-stage Ram-Pressed Briquettes

CONCLUSIONS

At the conclusion of Phase II of the overall project, the following conclusions can be drawn:

- Operation of the Phase II prototype cell over a total period of 33 power-on, plating days producing over 5 tonnes of dendrites has validated all aspects of the development program.
- The new cathode and anode designs have performed to expectations.
- The mechanical wiper design principle has been improved during the validation period to the point where consistent and essentially complete cathode wiping has been achieved on a commercial-size cathode.
- The new wiper material, Polyester PETP, shows good promise for achieving the correct balance between rigidity, flexibility and wear characteristics. Much longer operating periods will be required to confirm performance and maintenance requirements, which will be part of Phase III of the program.
- The polymer concrete cell has indicated no problems.
- The product conveyor has worked satisfactorily apart from some roller problems that will be readily overcome.
- Cell current efficiency was measured at 96%.
- Cell energy consumption was 1,425kWh per tonne of dry dendrite.
- Cell operation is essentially fully automated and shutdown and start-up procedures are minimal. The cathode operation does not suffer from power-off interruptions such as experienced in sulphate-based tankhouses.

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