

CADMIUM REMOVAL FROM COBALT ELECTROLYTE

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ABSTRACT

In order to meet the stringent specifications associated with the production of LME Grade A cobalt cathode, producers need to ensure that a number of impurities, including Cd, are removed from the advance electrolyte to ppb levels (~0.1 mg/L).

Conventional options include ion exchange using amino methyl phosphonic acid resin and solvent extraction using D₂EHPA. More recently a Cd-selective resin, employing Molecular Recognition Technology (MRT), became available from IBC Technologies, Inc.

These three potential unit operations were evaluated in parallel at Mintek. MRT was identified as the most technically feasible option. Results obtained on a cobalt advance electrolyte, containing 55 g/L Co, 6 mg/L Cd and 60 g/L Na₂SO₄, are presented in this paper.

1. INTRODUCTION

Cobalt metal specifications are stringent. For Grade A cobalt the specifications for Cu, Zn, and Cd are less than 30 mg/kg for Cu and Zn, and less than 10 mg/kg for Cd. In order to achieve these specifications, the cobalt advance electrolyte has to be adequately pure. Although the removal of impurities such as copper, zinc, and nickel has received significant attention in the past and has been implemented on a number of plants, information with regards to the removal of Cd is limited.

During recent years Mintek has been involved in numerous developing Cu-Co projects in Zambia and the Democratic Republic of the Congo. Some of the ores studied did not contain any Cd, while others contained low levels of Cd in the leach liquor that reported to the Co electrowinning circuit. In order to achieve < 10 mg/kg Cd contamination of the cathode, the Cd had to be removed to <0.1 mg/L from the advance Co electrolyte when operated with a ΔCo of 5-6 g/L across the electrowinning cell (undivided cell).

Various techniques such as precipitation, solvent extraction, and adsorption including ion exchange and molecular recognition, can generally be used to remove impurities to the required levels from advance Co electrolyte. This paper compares the performance of solvent extraction using di-2-ethylhexylphosphoric acid (D₂EHPA) and adsorption using an amino-methyl phosphonic acid resin (Purolite S950) and a molecular recognition product (SuperLig® 177, supplied by IBC Advanced Technologies) for the removal of Cd from an advance Co electrolyte.

2. MOLECULAR RECOGNITION TECHNOLOGY (MRT)

The Molecular Recognition Technology (MRT) process utilizes “lock and key”, or “host guest” chemistry. It is a highly selective, non ion exchange system, using specially designed organic chelators, or ligands that are chemically bonded to solid supports such as silica gel, or polymer substrates. The solid phase system consists of the bound ligand material, SuperLig®, packed into fixed bed columns that can be built in skid mounted modular form, and can be fully automated for continuous operation. The feed solution is passed through the column and the specific ion of interest is removed from the solution in a “lock and key” fashion. By utilizing “host-guest” chemistry, SuperLig® products are designed to selectively bind with ions based on multiple parameters such as size, coordination chemistry, and geometry. In contrast, conventional separation methods such as precipitation, ion exchange, and solvent extraction often recognize differences between ions based only on a single parameter (i.e. charge, solubility, size). SuperLig® products can bind ions even when they are present at extremely low levels in the presence of very high concentrations of competing ions and/or in highly acidic or basic solutions. Thus, MRT can be used to accomplish separations to very low levels that are not possible using other technologies.

The MRT process exhibits high selectivity, high binding factors, and rapid reaction kinetics, resulting in a very efficient separation. The simple elution chemistry produces highly concentrated solutions that can be easily treated to produce marketable products (99.9+% purity), of high added value, with minimal environmental impact. These metal products can be sold or recycled. This is an important factor from the standpoints of cost, the environment and waste disposal. A wide choice of eluent formulations is usually available to ensure compatibility with particular plant requirements. The SuperLig® materials exhibit long life. Due to high selectivity, high loading capacities, and rapid loading and release kinetics of the SuperLig® materials, application of IBC MRT results in substantially lower capital and operating costs than competitive technologies like ion exchange, solvent extraction, classical pH adjustment, and chemical precipitation procedures. Because relatively small quantities of the appropriate SuperLig® product are required, the scale of installation can be smaller, solution wash and elution chemical requirements and volumes are substantially less, and higher feed solution flow rates are possible. Higher efficiencies are possible due to single pass quantitative removal. SuperLig® materials have a long life and do not introduce any contaminants into the process. No regeneration of the SuperLig® product is required.

A schematic of the MRT process is shown in Figure 1. Sections 6 and 7 contain additional information on MRT and the application of SuperLig® products in the base metals industry.

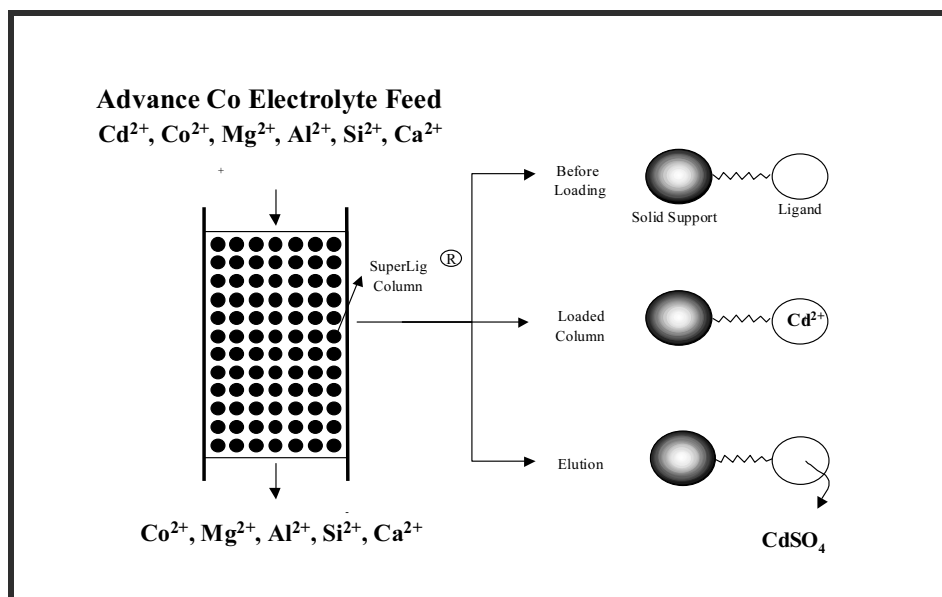


Figure 1. Schematic of MRT Process Cycle

3. EXPERIMENTAL SET-UP

3.1 Feed solution

A synthetic solution with a composition typical of a cobalt electrolyte solution in an undivided cell was prepared using the sulphate salts of the various elements. One batch of feed solution was prepared and used for the entire test program. The pH of the required amount of feed solution was adjusted to the desired value by the addition of a concentrated sodium hydroxide solution. No copper or zinc was added for this study, as the primary objective was to evaluate the potential of various extractants to remove cadmium.

3.2 Analysis

Solution samples were analysed by Mintek's Analytical Services Division. Cd was analysed by Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) with a detection limit of 0.01 mg/L. Other metals of interest were analysed by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) with a detection limit of 2 mg/L.

Each organic phase from the solvent extraction tests were first stripped with a 6M hydrochloric acid (HCl) strip liquor at an organic:aqueous (O/A) phase ratio of 0.5 and the resulting aqueous phase was analysed as described. HCl was used as a strip medium to ensure complete removal of all extracted metals from the organic phase, and to prevent any gypsum precipitation.

3.3 Adsorption test work

3.3.1 Resin pre-treatment

SuperLig[®] 177 product was pre-treated with sulphuric acid, followed by a water wash to remove entrained acid to a final resin pH of 2. The Purolite S950 resin was converted to the bi-Na form, through contact with a dilute sodium hydroxide solution. Excess sodium hydroxide was rinsed from the resin bed with water prior to being used.

3.3.2 Equilibrium loading isotherms

Equilibrium loading isotherms were established at a pH value of 2 for SuperLig177®, and at a pH value of 4 for SuperLig®177 and Purolite S950 resin (in the bi-sodium form). Portions of solution and resin were contacted in different ratios in roll-bottles for a period of 24 hours. After completion, the resin and barren solution were separated and the solution analysed for Cd.

3.3.3 Mini-column tests

Mini-column tests were conducted to obtain information on the kinetic performance of the SuperLig® 177 at pH values 2 and 4, and Purolite S950 at pH value 4. Experimental detail of the tests is provided in Table 1. Barren samples were collected in roughly 2-bed volume fractions and analysed for Cd by ICP-MS. (A bed volume is the volume of solution treated that is equal to the tapped volume of resin loaded into the column).

The flowrate for the test using Purolite S950 was adjusted to accommodate the expected slower kinetic performance of the resin, thus ensuring that immediate cadmium breakthrough would not occur.

Table 1. Experimental detail: mini-column tests

Resin		SuperLig® 177	SuperLig® 177	Purolite S950
Resin form		pH 2	pH 2	bi-Na
Resin volume	mL/test	15	15	60
Feed solution pH		2.1	4.1	4.1
Flowrate	BV/h ^[a]	2	2	0.8

[a] bed volume per hour (BV/h), where a bed volume equals the tapped volume of resin loaded into the column

3.3.4 Stripping

After completion of the mini-column tests, the resin was thoroughly washed with water to remove any entrained feed solution. It was critical to wash extensively as the Co concentration entrained in the resin was around 60 g/L. A two-stage elution procedure was followed, namely:

- (i) 2 bed volumes of weak acid eluant (1 g/L H₂SO₄), followed by
- (ii) 5 bed volumes strong acid eluant (100 g/L H₂SO₄).

Experimental conditions for the elution procedure followed are listed in Table 2.

Table 2. Stripping: experimental conditions

Pre-treatment		Water wash, in batch
Temperature	°C	50
Step 1: weak acid	g H ₂ SO ₄ /L	1
Volume	BV	2
Flowrate	BV/h	6.8
Step 2: strong acid	g H ₂ SO ₄ /L	100
Volume	BV	5
Flowrate	BV/h	6.8

The elution was performed in jacketed columns. Heated water was circulated through the jacket to ensure the temperature was maintained at 50 °C during the tests.

3.4 Solvent Extraction (SX)

All SX tests were conducted using the same feed solution as was used during the adsorption tests.

3.4.1 Effect of pH on extraction

The extent of extraction of the various elements at different pH values (S-curve) was determined. Feed solution was contacted with an organic phase comprising of 30 vol.% D₂EHPA in an aliphatic diluent (SSX210) at an O:A phase ratio of 2. The selected extraction pH was obtained by addition of either 200 g/L H₂SO₄ or 10M NaOH solution. All contacts were conducted at ambient temperature (~25°C).

3.4.2 Extraction equilibrium isotherm

Extraction equilibrium isotherms were generated at pH values of 2.0, 2.2 and 2.5 by contacting feed solution with the same organic phase as that used above (30 vol.% D₂EHPA in SSX210 diluent) at various O:A phase ratios. The pH of each contact was maintained at the desired value by the addition of 10M NaOH solution. All contacts were conducted at ambient temperature (~25°C).

4. RESULTS AND DISCUSSION

4.1 Feed solution

The composition of the feed solution used for the test work is provided in Table 3.

Table 3. Composition of feed solution, mg/L ^[a]

Cd	Co	Mg	Al	Si	Ca
6.7	57 850	4 630	24	49	15
Mn	Fe	Ni	Cu	Zn	Pb
844	10	<2	<2	<2	18

[a] Cd analyses by ICP-MS with a detection limit of 0.01 mg/L; other metals were analysed by ICP-OES with a detection limit of 2 mg/L Adsorption

4.1.1 Particle size distribution

The Purolite S950 resin used had a d_{50} (screen aperture through which 50% of the resin beads would pass) of ~0.57 mm (bi-Na form), with a particle size range of: +1.2 mm <5%, -0.3 mm <1%.

The SuperLig® 177 product is 250 – 500 microns, or 0.25 – 0.5 mm. in particle size, wet or dry.

4.1.2 Equilibrium loading isotherms

Equilibrium loading isotherms were established for the two adsorbents at pH values of 2 and 4. The results are depicted graphically in Figure 2. A substantial increase in Cd loading was observed for the SuperLig®177 product with an increase in pH, i.e. about 1.5 g/L Cd loaded at a pH value of 2, while the equilibrium loading was 2.9 g/L Cd (upgrading ratio of 480) at a pH value of 4. Both these concentrations were obtained at an equilibrium solution concentration of about 5 mg/L Cd. A loading of 0.05 g/L was obtained for Purolite S950 at pH 4 and a similar Cd solution concentration, which was an upgrading ratio of only 10.

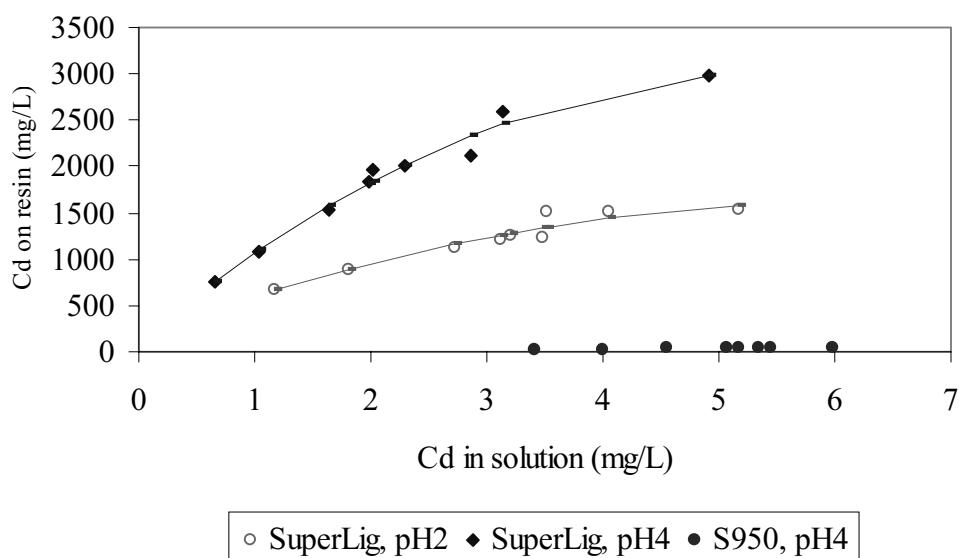


Figure 2. Equilibrium loading isotherms: SuperLig® 177 and Purolite S950

4.1.3 Mini column tests

Mini column tests were done in order to establish breakthrough curves for the two resins under the following conditions:

- SuperLig® 177, pH 2
- SuperLig® 177, pH 4
- Purolite S950, pH 4

The breakthrough curves are depicted graphically in Figure 3.

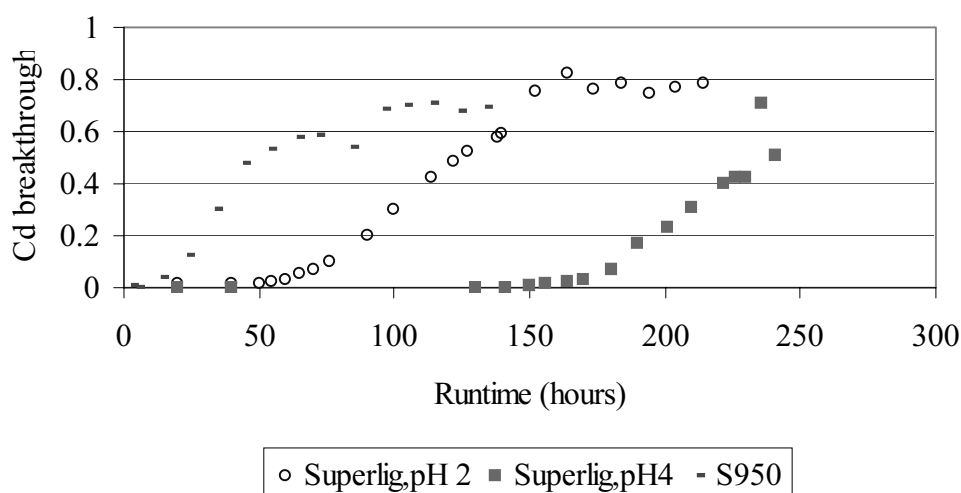


Figure 3. Breakthrough curves: SuperLig®177 and Purolite S950

The tests were stopped after approximately 70% cadmium breakthrough was achieved, i.e. the cadmium concentration in the barren solution exiting the columns was approximately equal to 70% of the cadmium concentration in the feed solution.

As can be seen in Figure 3, the slopes of the breakthrough curves for the two tests using SuperLig® 177 (pH 2 and pH 4) were similar, resulting in a similar resin inventory requirement for adsorption.

4.1.4 Selectivity factors

The selectivity factors for cadmium over the main metals present in the cobalt electrolyte solution (Co, Mn and Mg) were calculated for the different extractants at the different pH values tested. These factors were calculated as follows:

$$S_{Cd/metal} = (Cd \text{ on adsorbent} / Cd \text{ in solution}) / (metal \text{ on adsorbent} / metal \text{ in solution})$$

The selectivity factors determined for the various extractants are listed in Table 4. The SuperLig® 177 product exhibited excellent selectivity for cadmium over cobalt, magnesium and manganese, while Purolite S950 and D₂EHPA (results presented further on) showed very poor selectivities for cadmium over these metals.

Table 4. Selectivity factors for Cd over other metals

Extractant	Co	Mg	Mn
SuperLig®177, pH 2	30 300	256 450	3 550
SuperLig®177, pH 4	20 070	infinite ^[a]	2 850
Purolite S950, pH 4	16	213	5
D ₂ EHPA, pH 2.5	33	7	0.5

[a] no Mg loading recorded

4.1.5 Stripping and Co loss

A two-stage stripping procedure was followed for the resins, i.e. a weak acid (1 g/L H₂SO₄) strip, followed by strong acid (100 g/L H₂SO₄) strip. This was done in an attempt to obtain a selective elution between cobalt and cadmium loaded onto the resin, which would result in a lower cobalt loss from the impurity removal system. No clear separation between cadmium and cobalt was observed, as they stripped simultaneously. Hence, all cobalt loaded onto the resin will report to the cadmium-rich eluate stream. This stream will report to waste, thus any loaded cobalt will be considered a loss. The reason for the poor separation might have been the extremely fast flowrate employed, and further work should be done in order to optimise the selective strip if the co-loaded Co is a significant loss (such as with Purolite S950).

The majority of the loaded cobalt and cadmium reported to the eluate fraction between bed volumes 4 and 6. Employing a strong acid strip only, will decrease the volume of eluant required, and hence minimise the water balance issues around the Cd removal circuit. However, an efficient wash-step prior to elution is required to remove entrained feed solution. Again, this should be further investigated during more detailed test work.

The acid requirement, based on the elution procedure followed, was 300 kg H₂SO₄/m³ resin, which is unacceptable. The expected concentrations of cobalt and cadmium in the eluate, are listed in Table 5. Very little cobalt and cadmium reported to the first three bed volumes of eluate. This portion can be recycled within the elution circuit and used for acid make-up in subsequent elutions. The portion of the eluate consisting of bed volumes 4 to 6 contained the majority of cobalt and cadmium and will report to waste. The volume of eluate has to be minimised, i.e. recycling of a portion of this eluate fraction for the next elution cycle. The acid concentration should also be optimised, in order to minimise acid consumption. It is also recommended that the elution be carried out at lower flowrates to maximise the Cd concentration in a fraction of the eluate.

Table 5. Expected eluate fractional composition (g/L)

BV no	SuperLig® 177, pH 2		SuperLig® 177, pH 4		Purolite S950	
	Co	Cd	Co	Cd	Co	Cd
1 to 3	0.06	0.003	0.09	0.005	2.6	0.001
4 to 6	0.05	0.34	0.17	0.60	9.5	0.02

4.1.6 Neutralisation requirements

A further advantage of the SuperLig® 177 product is that it does not require any neutralisation prior to extraction. Purolite S950 requires neutralisation, and with the limited upgrading ratio achievable with this reagent, it will contribute to the bleed stream requirements from the electrowinning circuit.

4.2 Solvent extraction

4.2.1 Effect of pH on extraction (S-curve)

The effect of pH on the extent of extraction of selected metals by 30 vol.% D₂EHPA (S-curve) is illustrated in Figure 4. Data used for generation of the S-curve is given in Table 6.

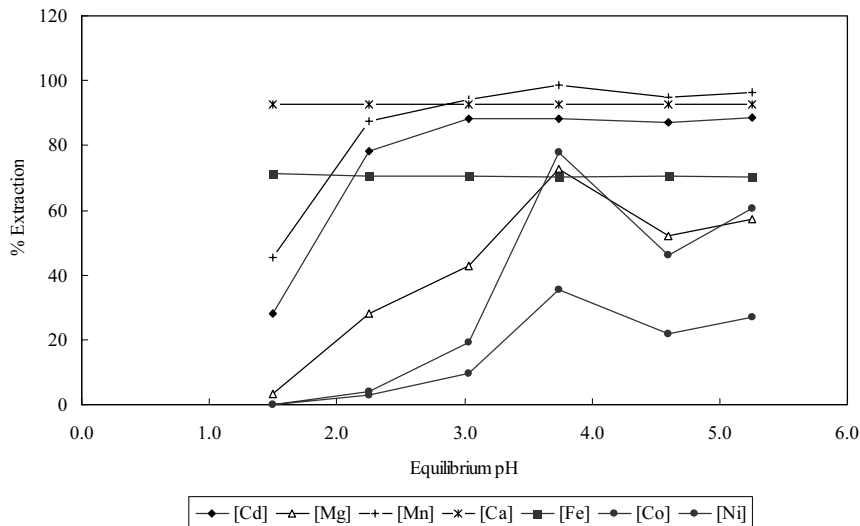


Figure 4. Extent of metal extraction versus pH (S-curve)

Table 6. D₂EHPA: S-curve data

pH	Extraction, %							
	Mg	Ca	Mn	Fe	Co	Pb	As	Cd
1.5	3	>93	45	71	0	0	99	28
2.3	28	>93	88	71	4	0	99	78
3.0	43	>93	94	70	19	22	17	88
3.7	73	>93	99	70	78	87	80	88
4.6	52	>93	95	71	46	53	46	87
5.3	57	>93	96	70	61	61	62	89

The pH versus degree of extraction (Figure 4) provides valuable information with regards to the pH values that could be targeted for extraction of a specific element. The optimum pH would be where maximum extraction of the impurity (cadmium) is achieved, whilst limiting the co-extraction of cobalt. For this test work the organic phase comprised of 30 vol.% D₂EHPA in an aliphatic diluent, SSX 210.

As the concentration of cadmium in the feed solution was only around 5 mg/L, and the targeted concentration in the treated solution was 0.1 mg/L, the inaccuracies around analysis make the evaluation of quantitative extraction difficult. Nevertheless, cadmium extraction was relatively effective with D₂EHPA. Some other characteristics of this

extractant need to be considered when evaluating it for the removal of cadmium, namely the co-extraction of Co, Ca, and Mn.

Co-extraction of cobalt on the loaded organic (prior to scrubbing) has to be limited as it increases the neutralisation requirement during extraction, which would have an adverse effect on the bleed stream requirement to maintain the sodium sulphate concentration in the electrowinning loop. The degree of cadmium extraction and cobalt co-extraction (based on electrolyte concentrations) at various pH values are listed in Table 7. Based on these results, it is clear that cadmium extraction would have to be done at pH values of 2.3 and lower where its extraction is reasonable, but the cobalt co-extraction is limited.

Table 7. Cd and Co extractions at various pH values

Equilibrium pH	Cd extraction, %	Co co-extraction, %	
		Full Co flow	Δ Co of 6 g/L
1.5	28	0	0
2.3	78	4	41
3.0	88	19	196

A 4% co-extraction of Co (of full Co flow) would result in a 12% bleed stream from the Co electrowinning circuit to maintain the sodium sulphate concentration at 50 g/L, which is unacceptable. This could be reduced significantly if an adequate number of extraction stages are allowed for so that Ca, Cd, and Mn can displace Co from the loaded organic prior to it leaving the extraction circuit.

From Figure 3 it can further be seen that Ca (28 mg/L in feed) and Mn (724 mg/L) were effectively extracted prior to Cd. The extraction of Ca would be an advantage, as it would prevent build up of Ca in the electrowinning circuit and hence reduce the potential of gypsum scaling. On the other hand, stripping of the organic will have to be well planned and operated, as gypsum precipitation will have to be avoided in the strip circuit.

The extraction of Mn from the advance electrolyte is a problem, as Mn is required at around 2 g/L in the electrolyte to protect the anodes from excessive corrosion. Furthermore, the extraction of a relatively high concentration of Mn and the associated consumption of NaOH to maintain the pH during extraction would result in a bigger bleed from the electrowinning circuit to control the sodium sulphate concentration.

4.2.2 Extraction equilibrium isotherm

The Cd extraction equilibrium isotherms generated for D₂EHPA at pH values of 2.0, 2.2 and 2.5 are illustrated in Figure 5.

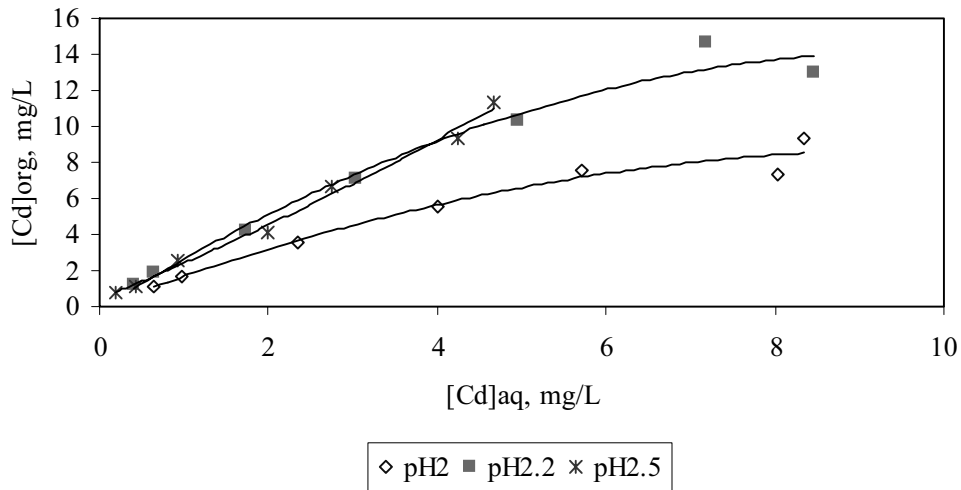


Figure 5. Cd extraction equilibrium isotherms

Similar organic loadings were achieved for pH values of 2.2 and 2.5 with an organic loading of ~10 mg/L in equilibrium with an aqueous concentration of 5 mg/L (the expected Cd feed concentration). The Cd loading when operating at a pH of 2.0 was ~7 mg/L in equilibrium with a similar aqueous concentration.

McCabe-Thiele analysis, performed on the pH 2.2 extraction isotherm to estimate stage and phase ratio requirements to achieve a target raffinate concentration of 0.1 mg/L Cd, is shown in Figure 6.

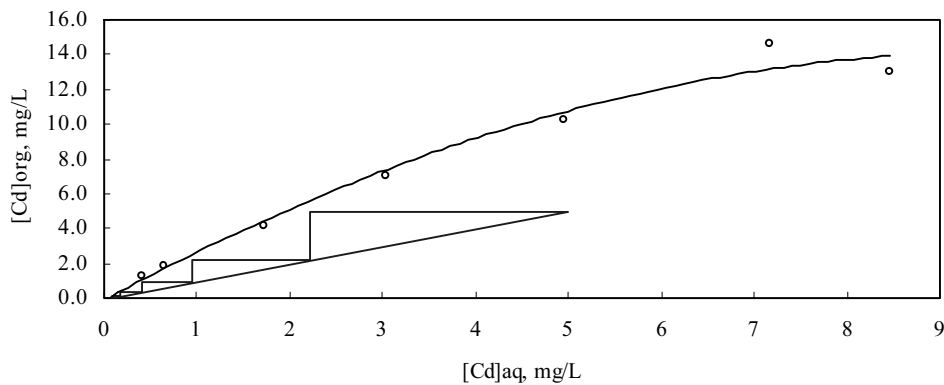


Figure 6. McCabe-Thiele analysis on pH 2.2 extraction equilibrium isotherm

The results of the McCabe-Thiele analysis are listed in Table 8. It should be possible to achieve the desired Cd concentration of 0.1 mg/L within 5 extraction stages.

Table 8. Results of McCabe-Thiele analysis performed on pH2.2 Cd extraction isotherm

O/A ratio	1.00
Feed, mg/L	5.00
Loaded organic, mg/L	4.92
Stripped organic, mg/L	0.02
Raffinate, mg/L	0.18
%Extraction	96.4%

Stage	Exit concentrations		Stage eff.
	Aq, mg/L	Org, mg/L	
E1	2.22	4.92	90%
E2	0.95	2.14	90%
E3	0.41	0.87	90%
E4	0.18	0.33	90%
E5	0.09	0.10	90%

4.3 Design Considerations

Results obtained during the mini-column tests were used to do an indicative sizing of the ion exchange circuit for the different resins and different feed pH values. An elution time of 1 hour was allowed for the SuperLig® 177 product, and 10 hours for the Purolite S950 resin (acidic elution and regeneration). A resin bed-height:diameter ratio of 2:1 was used as the minimum aspect ratio. Periodic backwashing is required to limit the pressure drop across the bed over a period of time. A freeboard (column height above resin bed) of 20% was allowed for backwashing. A feed throughput of 200 m³/hour was assumed.

The sizing was based on a lead-lag (2 columns in series) system. In a lead-lag configuration, feed solution is passed through two columns in series until a predetermined extend of breakthrough (usually ~80%) of Cd is achieved through the lead (first) column. Upon 80% breakthrough, the lead column is taken off-line and eluted. During this period, feed solution is directed to the lag (second) column, which now becomes the lead column. As soon as elution of the lead column has been completed, the eluted column is returned to the adsorption circuit in the lag position. It is necessary to contain enough resin in each column to ensure no Cd breakthrough would occur during the period when only one column is on-line in the adsorption circuit.

The size determined for the different options are listed in Table 9.

Table 9. Indicative sizing of adsorption circuits

		SuperLig®177, pH 2	SuperLig®177, pH 4	Purolite S950, pH 4
Feed composition:				
Cd	g/L	0.006		
Co	g/L	55		
Feed flowrate	m ³ /h	200		
Resin loading:				
Cd	g/L	1.04	1.85	0.1
Co	g/L	0.3	0.8	54
Residence time	hours	0.5	0.5	1.2
Elution time	hours	1	1	10
Number of columns		2	2	2
Resin volume: per column	m ³	101	101	367
Resin volume: total	m ³	202	202	733
Column diameter	m	4	4	5.5
Resin bed height	m	8	8	11
Column height	m	9.6	9.6	13
Co loss (to eluate) ^[a]		0.03%	0.05%	11%

[a] it was assumed that 100% of loaded Co will report to Cd-rich eluate stream

As shown in Table 9, the resin volume requirement for the Purolite S950 is substantially more than that required for SuperLig® 177. This is primarily due to the substantial increase in cadmium loading that can be achieved with the SuperLig® 177 product over that achievable with the S950 resin, and the much shorter elution period. IBC has operating experience indicating that the flow rate can actually be increased to 15 BV/hour. This will result in a much smaller column volume and SuperLig® 177 requirement than indicated above for the same Cd removal capacity.

All the cobalt co-loaded onto the resin will report to the cadmium-rich eluate stream for the SuperLig® 177 circuit. This stream would be a waste stream, meaning that all co-loaded cobalt has to be considered as a loss. With this reagent less than 0.05% of the cobalt in the feed to the ion exchange circuit would be lost.

The cobalt loss for Purolite S950 was substantially higher, at 11%. The cobalt loss for S950 was based on the assumption that 80% of the co-loaded cobalt will report to the weak acid portion during elution (achievable at a lower flowrate than that for SuperLig®177), while 20% of the cobalt will report to the cadmium-rich eluate stream.

5. CONCLUSIONS

The removal of cadmium (~6 mg/L Cd) from cobalt electrolyte solution (containing 55-60 g/L Co) was investigated. Three different adsorbents were evaluated in the pH range between 2 and 4, namely:

- SuperLig® 177
- Purolite S950
- D₂EHPA

Relatively high Cd loadings were obtained with the SuperLig® 177 resin, i.e. 2.9 g/L Cd from a feed solution containing ~6 mg/L Cd (upgrading ratio of 480). Poor loadings were achieved with Purolite S950 (0.1 g/L) and D₂EHPA (0.01 g/L). Cobalt co-loading on the SuperLig®177 adsorbent was relatively low, at <0.05% of the cobalt in the feed solution treated (based on a ΔCo of 6 g/L). Cobalt co-loading for Purolite S950 and D₂EHPA was substantially higher, i.e. 11% and 4%, respectively.

A further advantage of the SuperLig® 177 reagent is that no neutralisation is required prior to adsorption. This aspect is a major drawback for the D₂EHPA circuit. Furthermore, the extraction of Mn prior to cadmium poses another problem associated with the D₂EHPA circuit. The selectivity of this circuit for cadmium over cobalt is limited, which will put a high demand on the extraction circuit in that the cobalt content on the loaded organic has to be an absolute minimum in order to limit NaOH consumption associated with cobalt extraction. The cobalt loss anticipated for the Purolite S950 circuit (due to its relatively low selectivity for cadmium) makes this reagent unsuitable for this application.

Based on the results from this study, the SuperLig® 177 product appears to be the most attractive for the removal of cadmium from cobalt electrolyte. It is recommended that more test work is performed to optimise the elution circuit around the SuperLig® 177 impurity removal circuit and that an economic evaluation is done to ensure its feasibility for this application. The physical and chemical stability of the product has to be confirmed by recycling the resin bed numerous times. This would best be done on an operating plant.

There are a number of SuperLig® products that have proven to be economic for extraction of various impurities from cobalt as well as extraction from, and purification of, a number of other base metals. These are described in Section 6.

6. OTHER COMMERCIAL MRT SYSTEMS FOR THE BASE METAL INDUSTRY

Examples of other commercial MRT applications in the base metal industry include the following:

- 1) Extraction and polishing of the following impurities from cobalt bearing feed streams in sulphuric or nitric acid matrices:
 - a. Nickel
 - b. Copper
 - c. Zinc
 - d. Cadmium
 - e. Lead
 - f. Iron

- 2) Extraction of bismuth and antimony from copper refining electrolyte.
- 3) Extraction of mercury from concentrated sulfuric acid streams.
- 4) Extraction of copper from acid mine drainage streams.
- 5) Extraction and recovery of indium from primary mine streams, secondary scrap sources, and waste streams.
- 6) Extraction and recovery of germanium from zinc refinery electrolyte.
- 7) Extraction and recovery of nickel from cadmium sulfate streams.
- 8) Extraction and recovery of platinum group metals from electrolytic copper refinery streams.

7. REFERENCES

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