MOVING BED ION EXCHANGE DESORPTION FOR BASE METALS PROCESSING

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ABSTRACT

Ion exchange technology is typically considered in base metals hydrometallurgical flowsheets for (a) primary recovery of the value metal from clarified solutions or difficult-to-filter slurries/pulps and (b) purification of the crude metal streams.

Numerous process and equipment options exist in configuring the adsorption step of the ion exchange process, including fixed bed and moving bed approaches. However, in base metals processing, the possibilities for the desorption step are usually limited to a fixed bed configuration, using single column, multi-column, or carousel systems. In some sense, these limited options have hindered the deployment of ion exchange systems into base metals hydrometallurgical flowsheets. The single fixed bed approach suffers from an unfavourable water balance, with significant stream recycling required to manage reagent consumption and with a substantial dilution of the value metal in the eluate going forward to downstream processing (i.e. the concentration of the metal in the eluate is much lower than the concentration of the metal on the resin). The multi-column or carousel approach improves reagent utilisation and eluate tenor. Still, it cannot be integrated easily with moving bed ion exchange processes (including all resin-in-pulp (RIP) applications and systems such as NIMCIX or CLEAN-IX® CLX). Given their fixed bed nature, the single column and multi-column carousel are poorly suited from an operational point of view for desorption processes that can form precipitates (e.g. gypsum) or suffer from solids carryover.

This paper presents opportunities in the base metals industry where moving bed desorption, particularly the use of the U-shaped desorption column, offers operational and economic advantages over fixed-bed approaches.

Firstly, the basic principles of base metal desorption from ion exchange resins with iminodiacetic acid (IDA) and aminomethylphosphonic acid (AMP) functionalities are presented. Case studies demonstrate how moving bed ion exchange desorption using the U-shaped column can provide (a) simultaneous purification and value metal upgrade; (b) decreased cross-contamination between value metal and impurity bleed streams and; (c) close-to-stoichiometric reagent consumption.

Incorporating moving bed desorption into base metals ion-exchange flowsheets, using the U-shaped column, has the potential to unlock significant project value. This value will come from reduced ion exchange reagent requirements, higher tenor eluate, reduced hydraulic load for downstream processing, and/or additional downstream processing options. In many cases, this increase in project value will be the deciding factor on a project's viability.

Keywords: ion exchange, base metals, counter-current desorption, U-shaped moving bed column

INTRODUCTION

Ion exchange (IX) is a well-established hydrometallurgical process with the base metals industry typically considering this technology for:

- Bulk recovery of base metals from complex to filter slurries and pulps [1], [2];
- Recovery and upgrade of the metals from dilute (<0.5 g/L) clarified solutions [3], [4] and;
- Impurity removal from crude metal streams [5], [6], [7], [8].

The two conventional ion exchange resin functionalities of broad interest in base metals processing are:

- Iminodiacetic (IDA) chelating ion exchange resin – considered for primary recovery of base metals such as Cu, Ni, Co and Zn from process liquors and pulps;

- Aminomethylphosphonic (AMP) chelating ion exchange resin – used in purification and refining of Co and Ni-bearing streams or electrolytes, typically for rejection of impurities such as copper and zinc, and occasionally cadmium.

In primary recovery applications, metal upgrade onto the resin phase is a strong indicator of process economics and attractiveness. In purification applications, specific impurity upgrade onto the resin and the extent of value metal co-loading (separation factor) is crucial.

It is widely accepted that, following metal upgrade onto the resin phase, its concentration will be diluted at least 2-times in the subsequent desorption process. This is indeed the case when desorption is performed in either fixed bed or straight moving bed columns. However, when desorption is conducted in a U-shaped moving bed column, value metal dilution can be avoided, and its concentration may even be further upgraded and partially purified, as demonstrated by Sunrise Energy Metals' flagship Sunrise Project [2].

This paper outlines the underlying chemistry, metallurgical testwork, process design criteria generation, and resultant project benefits the U-shaped desorption column can bring to a range of base metal applications, including:

- Single element recovery, such as copper (IDA resin), from mine wastewater;
- Nickel and cobalt recovery from laterite HPAL pulp (IDA resin);
- Zinc polishing from a high-grade nickel-cobalt liquor (AMP resin);
- Zinc and cadmium removal from cobalt liquor (AMP resin).

BACKGROUND INFORMATION

Principles of ion exchange resin desorption

Desorption (also known as elution, stripping) involves contacting the metal loaded resin with the required volume of sufficiently concentrated desorbing reagent. This is typically a mineral acid (H_2SO_4, HCl) for IDA and AMP resin, although alternative reagents can be used (e.g. ammoniacal solutions). Various approaches can be taken to perform this contact, which influences eluate composition, residual metal loading on the resin, and reagent consumption. As examples [9]:

- If the metal loaded resin is batch contacted with the desorbing solution (eluant) at a resin-to-liquor ratio of 1-to-50, the desorption process will be at equilibrium in 0.5-2.0 hours with 95-99% of the metal having been stripped from the resin. However, the metal concentration in the resulting product solution (eluate) will be 1/50th the concentration on the resin, and the eluate will also contain a large quantity of desorbing reagent, neither of which facilitates economical downstream processing.

- Thus, desorption processes are typically performed in cylindrical columns. Along the length of this column, a concentration gradient will exist in the resin and solution phases – this gradient results in an eluate with maximum metal and minimum free reagent concentrations. This sees utilisation of the desorbing reagent being as close as possible to the stoichiometric requirements of the desorption reaction [10], [9]. This approach is illustrated in Figure 1, where fixed-bed column elution occurs by passing eluant up-flow at 1 BV/h flowrate.

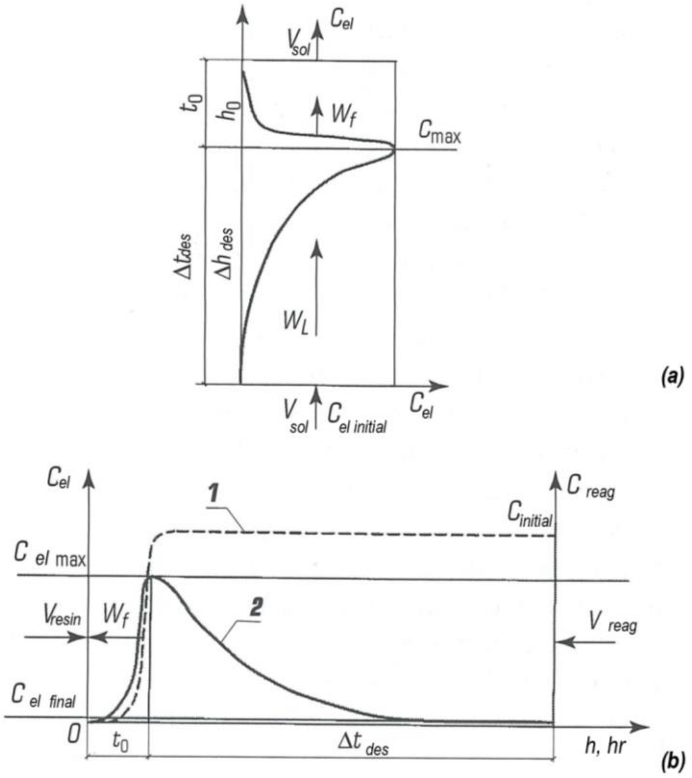

Figure 1: Distribution of the element during desorption/ mass transfer zone (MTZ) formation [9]

(a) – concentration profile inside of the desorption column; (*b)* – elution curve
1 – adsorption profile of eluting reagent; *2* – desorption curve of metal

C_{el} – element concentration in the eluate, g/L; C_{reag} – concentration of the desorption reagent in the eluate, g/L; $C_{el\ final}$ – element concentration in the eluate at the end of desorption, g/L; W_f – linear velocity of the desorption mass transfer zone, m/h; t_0 – time of MTZ formation, h; Δt – time required for the element desorption, h; h_0 – the height of the MTZ movement during time t_0, m; Δh – the height of the resin bed where the concentration of the element in solution increases from C_{final} to C_{max} (decreases in the resin phase from E_{loaded} (E_{max}) to residual E_{res}).

The characteristics of the fixed bed elution curve seen in Figure 1 are described in more detail to demonstrate the role the column configuration can have on elution outcomes:

- The desorption process commences once the reagent contacts the loaded resin. As the concentration of the desorbing reagent is high, this process usually is not kinetically constrained.

- For a short period (0.4-0.5 h), desorbing reagent does not appear in the effluent solution. During this time (a) interstitial water entrained in the resin is displaced, and (b) intensive adsorption of the reagent/displacement of the loaded element occurs.

- Full saturation of the resin bed with eluant is complete within 1.0-1.5 h. The concentration of the desorbed element in the liquor phase moves upwards through the column with the flow of desorbing reagent. At a certain height (Δh), this concentration reaches its maximum (C_{max}) value, being at equilibrium with the element concentration in the resin phase (E_{max}). The time required to reach maximum concentration (C_{max}) corresponds to the time required to form the desorption mass transfer zone (t_0).

- As the eluant flows into the column continues, the MTZ shifts upwards. Eventually, the effluent composition equals the eluant composition.

In the case of a moving bed column, the resin phase concentration of the element being desorbed decreases in the direction of the resin movement. The concentration of the desorbed element in the liquor phase increases upwards along with the working height of the desorption column (Δh), with C_{max} occurring close to the eluate outlet. As such, desorption in straight moving bed columns typically guarantees the overall eluate metal concentration is 0.75-1.00 of the maximum concentration (C_{max}) [9].

U-shaped moving bed desorption column

Since its first deployment in the late 1980s, desorption of SBA-type resin in a U-shaped moving bed column has become the standard flowsheet in Kazakhstan for processing low-grade uranium leachates at in-situ recovery operations. Wider use of the U-shaped column for desorption of other metals was not implemented within the former USSR, primarily due to limited information exchange between critical elements (uranium, tungsten, etc.), gold and base metals industries [9].

The key benefit the U-shaped column provides over other styles of desorption columns is its ability to produce eluates with exceptionally high concentrations. This concentration effect is typically accompanied by partial purification and near-stochiometric reagent consumption. The concentration effect occurs due to the presence of various “zones” in the U-column, as presented in Figure 2.

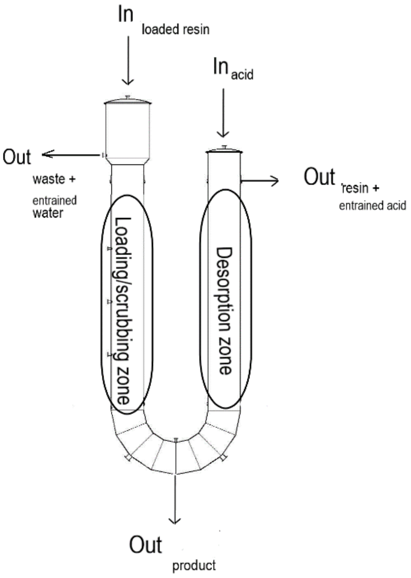

Figure 2 – Sections of the U-shaped moving bed desorption column [11]

As the resin moves through the column, it first encounters the “loading/scrubbing zone”. Here, dilute desorbing reagent exchanges for low-affinity impurities and/or, due to contact with eluate, the targeted metal (e.g. uranium) crowds off lower affinity impurities (e.g. iron and thorium anionic species). The resin exiting the loading/scrubbing zone is enriched in the targeted metal and depleted in impurities.

The resin then encounters the “desorption zone”. Here, contact with concentrated eluant occurs, and desorption takes place. The counter-current flow of resin and eluant results in a low residual resin phase metal concentration.

It is recognised that the U-shaped column is a larger, more specialised vessel than a typical fixed bed ion exchange column. The cost of such a vessel needs to be considered against the benefits/additional processing opportunities. The price of the standard U-shaped column described in Table 1 is in the range of USD 380 – 480 ex. works (indicative price, which will vary depending on the material of construction selection).

Table 1: U-shaped column dimensions and characteristics

Resin throughput capacity	5.0-7.5 m^3/h (for desorption of chelating resin)
Eluant capacity	Not a constraint, but typically 6 – 10 m^3/h
Total resin volume	~60 m^3
Diameter	1.50 m
Working height,	Individual leg height ~11 m, overall length ~26 m
Overall height, m	~17 m

Elution of base metals from IDA resin using U-shaped desorption columns was selected for the Sunrise Project flowsheet [2]. This column can be easily integrated with Resin-in-Pulp or any other adsorption configuration where resin moves between the vessels (NIMCIX, CLEAN IX CIX, etc.).

METALLURGICAL TESTWORK

The first step in desorption process development for fixed bed and straight moving bed contactors is a generation of the desorption profile (see Figure 1). In contrast, the first step in desorption process development for U-shaped moving bed contactors is a generation of the equilibrium desorption isotherm. Combined, this profile and isotherm provide an early, objective way of selecting the best desorption column for an application. Following selection, continuous piloting can be contemplated.

The initial operating parameters for continuous piloting in a U-shaped column (such as eluant (acid) strength and flow, eluate flow, frequency of resin transfer) can be inferred from the desorption profile and desorption isotherm. The main process streams associated with the U-shaped column are shown in Figure 2, and Figure 3 shows the corresponding streams on a U-shaped column test rig. General operating parameters for such a rig are summarised as:

Resin inventory:	600 mL
Column internal diameter:	20 mm
Resin transfer volume:	40-60 mL (volume of resin periodically added/removed from the rig)
Resin transfer frequency:	Every 1.0 hour
Eluant addition rate:	variable
Eluant strength:	variable
Eluate flow:	variable
Waste (recycle solution) flow:	variable
Temperature:	controlled to target

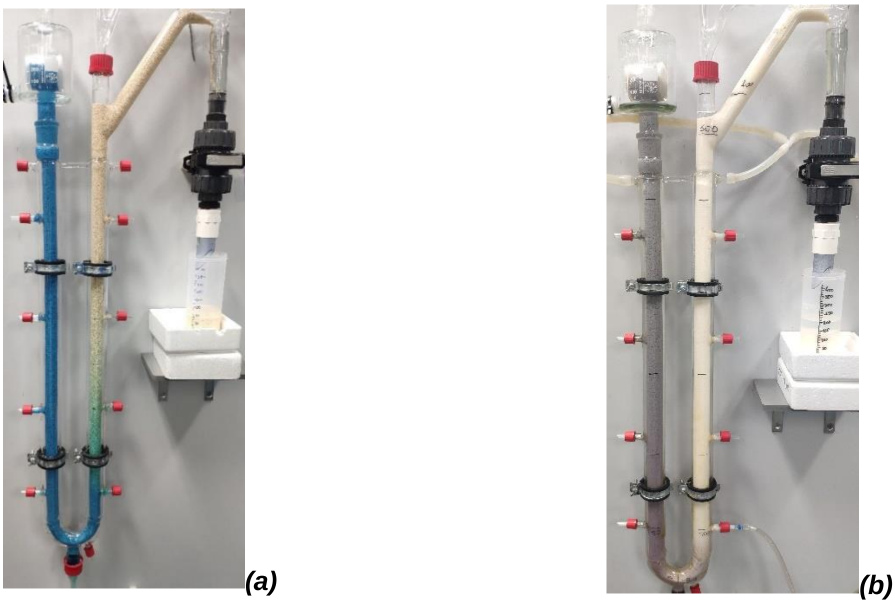

Figure 3 – U-shaped column test rig:

(a) copper desorption (b) selective elution - Zn separation from Co and Ni

Recently four (4) U-shaped column pilot campaigns have been executed for base metals applications with the following objectives:

(1) Copper – demonstrate maximum copper concentration in the eluate and minimal residual H_2SO_4 concentration. These targets were set to evaluate direct downstream (i) copper sulfate crystallisation and (ii) electrowinning.

(2) Nickel and Cobalt – assess the possible Ni and Co upgrade into eluate and simultaneous purification from the main impurities (Mg and Mn) typically present in nickel laterite HPAL flowsheets;

(3) Impurity Removal – Quantify performance of the U-column in “split elution” applications such as Zn polishing from high-grade mixtures of Ni and Co. Value metal recycle / loss and impurity metal recycle / loss is critical in this application.

(4) Impurity Removal - Cd and Zn polishing from Co-bearing liquor.

The resin and liquor compositional profiles were characterised at the end of the above-mentioned pilot campaigns. This was achieved by sequentially off-loading 60-80 mL portions of resin/solution from the column. Contact liquors and eluates were analysed for the metals of interest, and resin samples were stripped to assess metal loading.

These profiles have proven to provide additional desorption process insights.

RESULTS AND DISCUSSION

In this section, results from the four U-shaped column pilot campaigns are provided with a discussion of the process implications.

Iminodiacetic resin: bulk metal recovery, upgrade, and partial purification

Copper upgrade

Iminodiacetic resin is well suited to copper recovery from dilute streams due to the resin's high copper selectivity and loading capacity.

Copper equilibrium desorption isotherm generated via batch contacts of loaded IDA resin with 150 g/L H_2SO_4 is presented in Figure 4. The free sulfuric acid concentration measured in each equilibrium point is also provided.

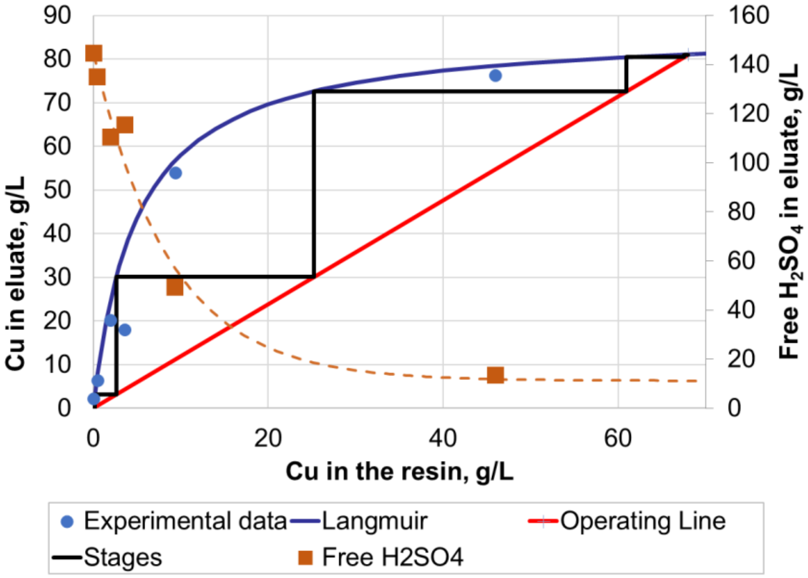

Figure 4 – Copper desorption isotherm

It indicates that copper upgrade into the eluate can be achieved if the flow ratio of eluate to resin is below 1. Under such conditions, the residual acid concentration in eluate is less than 15 g/L H_2SO_4.

For desorption in straight columns (fixed bed or moving bed), a flow ratio <1 cannot be practically achieved. However, desorption in a U-shaped moving bed column permits flow ratios of <1.

Against this context, U-shaped moving bed column piloting was undertaken to verify the operating parameters required for:

(a) production of copper eluate containing ~ 80 g/L Cu and low residual concentration of H_2SO_4,
(b) complete desorption of the resin (residual loading <0.5 g/L Cu);
(c) minimum copper deportment into the recycle stream.

IDA resin loaded with 68 g/L Cu was desorbed in a 0.6 L U-shaped column (see Figure 3 (a)) using two different strengths of sulfuric acid (150, 200 g/L H_2SO_4). According to the McCabe-Thiele construction presented in Figure 4, to achieve 80 g/L Cu eluate from the resin containing 68 g/L Cu, an eluate-to-resin flow ratio of 0.85 should be targeted. Based on acid demand determined during fixed-bed column elution tests, the minimum volume of eluant required for elution with 150 g/L H_2SO_4 should be 1.4 BV and 1.04 BV when 200 g/L H_2SO_4 is used.

At the beginning of the trial, ~40% of the column was loaded with IDA resin in the H^+-form (right leg of the column) and the rest ~60% of the volume with Cu^{2+}-loaded resin. Acid flow into the column was initiated with resin transferred hourly. For the first 15 hours of operation (15 transfers), all the solution was directed to the recycle stream (i.e. no eluate flow). Once the copper metal was observed in the waste stream, copper eluate started to be withdrawn from the bottom of the U-shaped column. The initial eluate-to-resin ratio was intentionally kept below 0.85 to minimise the time required to reach a steady state.

Copper concentrations observed in the eluate and recycle streams are shown in Figure 5, and a summary of input and output parameters is given in Table 2.

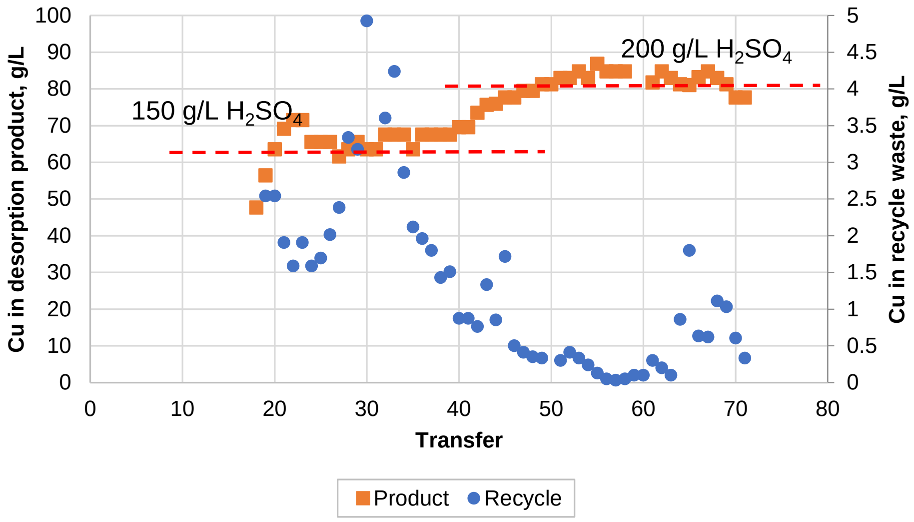

Figure 5 – Copper concentration profile in eluate and recycle streams

Table 2: Outcomes of the counter-current desorption of Cu-loaded resin

Condition#	Unit	1	2
INPUT			
Loaded resin Cu	g Cu/L acid form resin	68	68
Loaded resin flow IN	mL/h	42	44
	BV/BV	1.00	1.00
Eluant H_2SO_4 concentration	g/L	150	195
Eluant flow IN	mL/h	59	50
	BV/BV	1.41	1.13
OUTPUT			
Eluate flow OUT	mL/h	31	35
	BV/BV	0.74	0.79
Eluate Cu concentration	g/L	64	81
Eluate pH		1.7	1.5
Eluate free H_2SO_4 concentration	g/L	5	10
Acid consumed	eq H^+/eq Cu desorbed	2.0	2.1
Recycle flow OUT	mL/h	28	23
	BV/BV	0.67	0.52
Recycle Cu concentration	g/L	2.73	0.5
Recycle pH		2.6	2.6

Eluate copper concentration at Condition 1 (150 g/L H_2SO_4 eluant) increased to a peak concentration of 71 g/L Cu (transfer #22-23) before stabilising at ~64 g/L Cu. The corresponding eluate residual acid concentration was ~5 g/L H_2SO_4. Copper concentration was below the targeted 80 g/L Cu, and the recycle stream at >2 g/L Cu also represented a suboptimal copper deportment.

Acid strength was therefore increased to ~200 g/L after resin transfer 32, and the impact was seen by transfer 48. Eluate copper concentration was stable and averaged ~80 g/L Cu over the following 20 transfers, with minimal copper deportment to the recycle stream. The corresponding eluate residual acid concentration was ~10 g/L H_2SO_4. Residual copper concentration in the resin phase was consistently below 0.5 g/L.

Results of the pilot campaign confirmed that desorption of copper loaded IDA resin in a U-shaped column allows one to:

- operate on the desorption equilibrium curve;
- generate rich copper eluate with minimum residual acid in the product;
- utilise acid close to stoichiometric requirements;
- unlock downstream processing options for generated eluate like direct crystallisation or electrowinning.

Nickel and cobalt upgrade with simultaneous purification via bulk rejection of Mg and Mn

As per the previously described approach, a desorption equilibrium isotherm was determined for nickel-loaded resin, followed by U-shaped column piloting. In this case, IDA resin was loaded using partially neutralised pulp from nickel laterite HPAL (see leachate and loaded resin composition in Table 3). At the end of piloting, resin phase and solution phase concentration profiles along the length of the U-shaped column were determined.

Based on the nickel desorption equilibrium isotherm in Figure 6, resin loaded with ~36 g/L Ni can potentially generate eluate containing ~80 g/L Ni if desorbed in the U-column at an eluate to resin flow ratio of ~0.45.

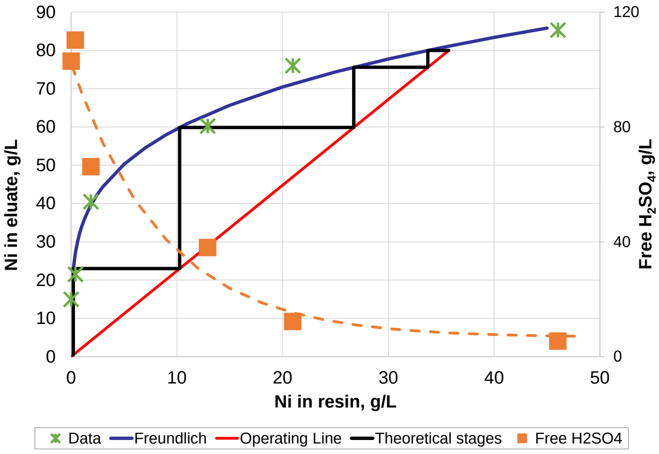

Figure 6 – Nickel desorption isotherm at 40℃

The following operating conditions were chosen for the U-shaped column piloting:

Resin flowrate (desorbed)	63 mL/h = 1.0 BV/BV
Acid concentration	250 g/L
Acid flowrate	44 mL/h = 0.7 BV/BV
Eluate flowrate	28 mL/h = 0.45 BV/BV
Operating temperature	40°C

In total, 85 resin transfers were accomplished, equal to ~8.5 full inventory turn-overs of the test rig. Outcomes of the campaign are summarised in Table 3, and the eluate concentration profiles of the major elements are presented in Figure 7. The free acid concentration in the eluate product on average was 5-10 g/L H_2SO_4.

Table 3: Outcomes of the counter-current desorption of resin loaded from Ni/Co laterite matrix

	Co	Mg	Mn	Ni	Zn
Feed liquor (for resin loading), g/L	1.9	6.1	5.9	7.3	0.24
Resin loading, g/L	6.5	1.6	5.6	35.7	1.2
Desorption product, g/L	10.1	0.03	4.1	77.4	2.2
Metal deportment to eluate, %	80	0.8	33	97	81
Upgrade from resin to eluate	1.6	0.02	0.7	2.2	1.8
Upgrade from feed liquor to eluate	5.3	0.005	0.7	10.6	9.2

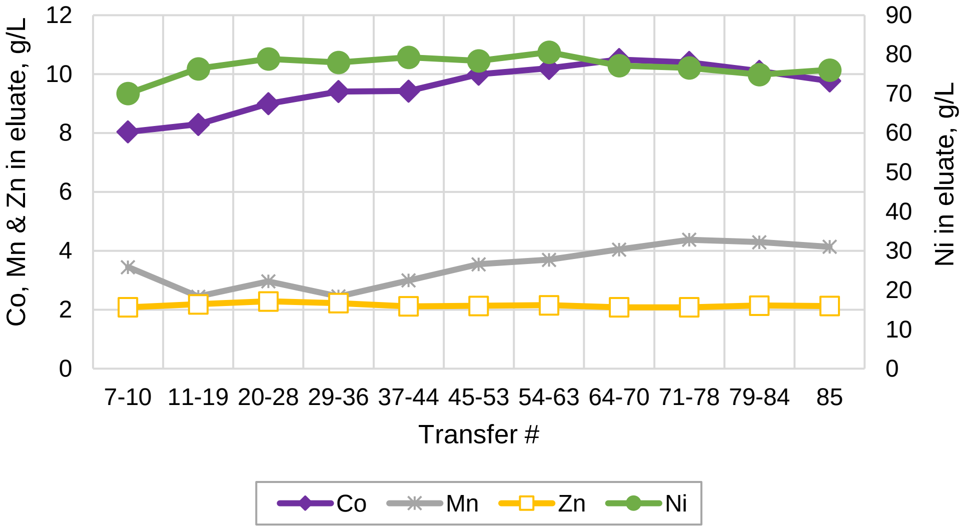

Figure 7 – Metal concentrations in eluate during U-shaped column piloting

The extent of metals upgrade into the eluate followed the selectivity sequence typical of IDA resin, i.e. $Ni^{2+}>Zn^{2+}>Co^{2+}>Mn^{2+}>Mg^{2+}$. This shows that the deployment of U-shaped column desorption as a part of a base metals processing flowsheet can enhance the selectivity function of the resin being used.

Profiling the column at the end of the campaign resulted in the resin phase and solution phase profiles seen in Figure 8. The column was profiled at the end of the desorption cycle (before transfer), and the composition of the eluate withdrawn is included to characterise metals distribution in the liquor phase.

In the scrubbing/adsorption zone (normalised cumulative column volume 0 – 40%):

- As loaded resin entered the left leg of the column, resin phase concentrations of Mg, Mn, and Co decreased by 94%, 32% and ~9%, respectively, primarily due to the decrease of the solution phase pH from ~4 to 3.
- Steady decrease of Mn concentration in the resin phase due to scrubbing with Ni (peak Ni concentration in the resin was ~ 38 g/L).
- Peak solution-phase concentrations of Co (14 g/L) and Mn (10 g/L) are seen in this zone.
- Decrease in pH values from 4 down to 1.7 (not shown in Figure 8). The free acid concentration measured in the eluate product was ~10 g/L.

In the desorption zone (normalised cumulative column volume 60 – 100%):

- Residual metal loading on the resin was near-zero.
- Eluate was withdrawn at normalised cumulative column volume ~50%. This is seen to coincide with peak nickel concentration in the solution phase of ~77 g/L Ni.

There is an opportunity to increase Ni concentration in the eluate further by increasing the concentration of sulfuric acid feeding the column. The extent of internal cobalt metal recycling can be optimised by changing the eluate flow ratio if required. However, this will impact total nickel concentration in the eluate. Depending on the specific needs of the project, different desorption strategies can be implemented.

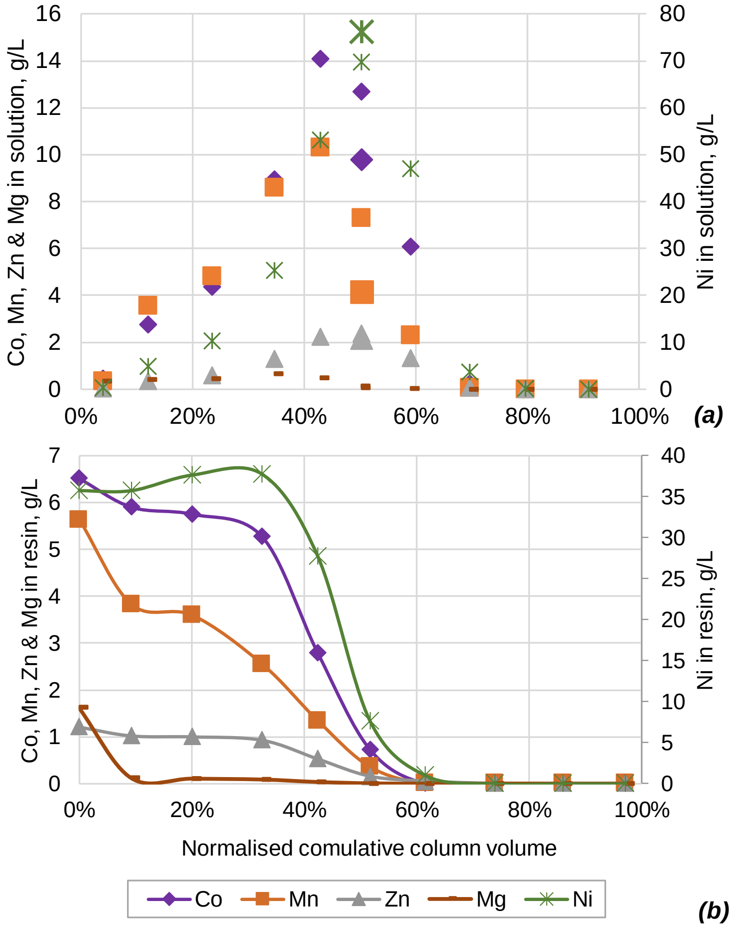

Figure 8 – Metals distribution between liquor (a) and resin (b) phases at the end of the campaign

The enlarged marker represents the metal concentration in the eluate

Aminomethylphosphonic resin: value metal purification

Ion exchange technology allows impurity removal to <1 mg/L level and is typically considered a purification step in the production of high purity base metals electrolytes or their salts. However, due to the limited selectivity of ion exchange resins (relative to extractants in SX, for example), co-loading of the value metal can be significant and may result in an overall value metal loss.

Two recent U-shaped column pilot campaigns, however, have demonstrated very favourable performance in purification applications, whereby AMP resin was used for:

1) Zn polishing from a high-grade mixture of Co and Ni, and;
2) Cd and Zn removal from Co-bearing solution.

Impurity removal from high-grade Ni, Co liquor

A Ni-Co liquor containing 1000 mg/L Mn and 25 mg/L Zn was treated by passing it through a moving bed column filled with AMP resin at a 188:1 ratio (see composition in Table 4). The resulting loaded resin was homogenised and used for both fixed-bed split desorption and U-shaped column moving bed desorption. This loaded resin carried 1% of feed Co and 0.4% of feed Ni.

Under split desorption, co-loaded value metal is first desorbed using weak acid (10 to 20 g/L H_2SO_4), followed by desorption of impurity metal and residual value metal using strong acid (50 to 100 g/L) [8]. Acid strength/acid volume conditions are optimised to target an 80/20% split, meaning 80% of value metal loaded onto the resin is recycled back into the circuit carrying 20% of the impurity load, and 20% of the value metal is lost with the impurity-bearing stream (80% of the impurity load).

Table 4 contains the results of this split desorption approach in a fixed bed column. At the nominated acid strengths and volumes, the split of Zn between recycling and reject streams was 21 and 79%, respectively. In contrast, the separation of Co and Ni between those streams was 64/36 and 70/30%, respectively.

Table 4: Zn polishing from Co-Ni mixture

Parameter	Co	Mn	Ni	Zn
Resin loading (for both split elution and U-shaped column testwork)				
Composition of feed liquor for purification, g/L	4	1	30	0.025
Loaded resin, g/L	7.5	3.5	23.7	4.7
Upgrade from liquor to loaded resin	1.9	3.5	0.8	188
Loading as % of feed value metal	1.0	--	0.4	--
Fixed bed split desorption				
Recycle flow (weak acid)	4 BV/BV of 10 g/L H_2SO_4 at 2 BV/h flowrate			
Reject flow (strong acid)	2 BV/BV of 50 g/L H_2SO_4 at 2 BV/h flowrate			
Metal deportment into the recycle stream, %	64	34	74	21
Metal deportment into the reject stream, %	36	66	25	79
Recycle composition, g/L	1.2	0.3	4.4	0.25
Reject composition, g/L	1.35	1.15	3	1.85
Total metal upgrade into the reject stream	0.34	1.15	0.10	74
Zn separation factor	219	64	740	1
U-shaped column desorption				
Recycle flow, BV/BV	1.3 BV/BV			
Reject flow, BV/BV	0.3 BV/BV			
Metal deportment into the recycle stream, %	84	34	90	2
Metal deportment into the reject stream, %	16	66	10	98
Recycle composition, g/L	5.3	1.1	17.4	0.1
Reject composition, g/L	4.4	9.0	8.8	17
Metal upgrade into the reject stream	1.1	9	0.3	680
Zn separation factor	618	76	2318	1

Table 4 also contains results for the U-shaped moving bed desorption approach. Using the same loaded resin and 100 g/L H_2SO_4 as the eluant, the metals split between recycle/reject streams was 2/98 % for Zn, 84/16% for Co and 90/10% for Ni. The improved sharpness of this split during desorption leads to the following process benefits:

- Decreased value metal loss. Relative to feed liquor, fixed bed desorption Co/Ni loss was 0.36% and 0.11%, whereas U-shaped column desorption Co/Ni loss was 0.18% and 0.05%. More than 50% reduction in Co loss and Ni loss. Commercially, this corresponds to additional revenue.

- A reduction in the recycle of impurity units (Zn) back to the impurity polishing circuit from 21% to 1% (i.e., a ~90% reduction). The impurity removal circuit is sized for Zn flow; a decrease in internal recycling reduces that removal circuit's size (and cost).

- Significant upgrade of impurity into the reject stream, with fixed bed desorption achieving 1.8 g/L Zn against the U-shaped column's 17 g/L Zn. The free acid concentration in the reject stream was ~30 g/L free H_2SO_4. The concentrated, small volume reject from the U-shaped column opens opportunities to use other technologies (precipitation, solvent extraction, etc.) downstream to increase value metal recovery further.

- Selectivity of the ion exchange resin's functionality is optimally utilised, as seen by the three-fold increase in the impurity/value metal separation factor when comparing the U-shaped column outcomes to the fixed bed split desorption outcomes.

Profiling of the U-shaped column at the end of the desorption campaign is presented in Figure 9.

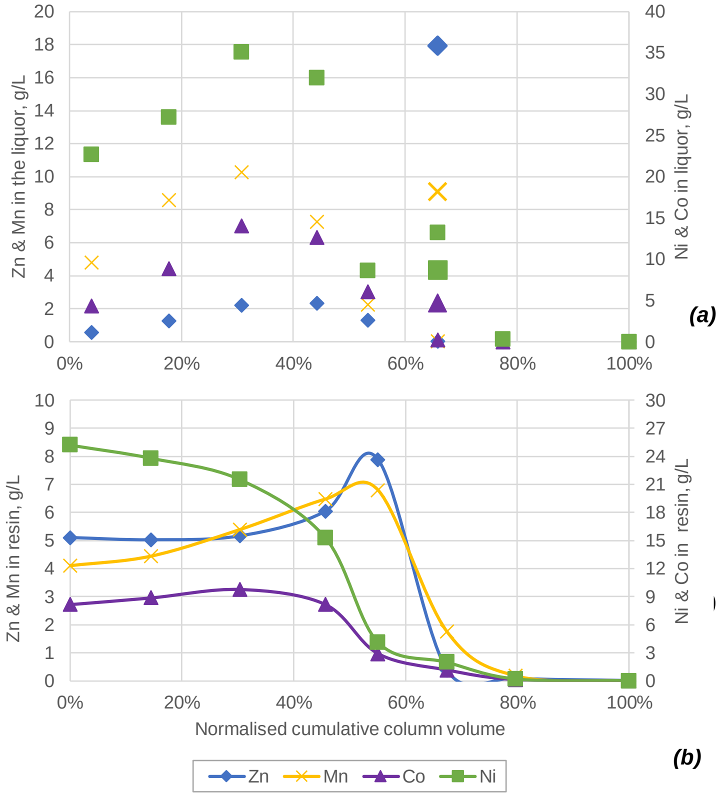

Figure 9 – U-column profile after spit elution of Co and Ni from Zn

The reject stream was collected on the right-hand side of the column (at ~65-70% normalised cumulative column volume) to minimise the cross-contamination of the high-grade Co/Ni and Zn/Mn streams. The majority of Zn was concentrated in the desorption zone of the column, with Zn concentration reported into the reject stream being at least six times higher than in the scrubbing zone of the column. Scrubbing of Ni and Co from the resin phase was achieved by enriched concentrations of Zn (~2 g/L) and Mn (~8 g/L) in the liquor phase. Nickel was more effectively scrubbed than cobalt due to the difference in the selectivity of AMP resin towards these elements. This indicates that AMP resin is well suited to Zn impurity removal from nickel sulfate and its more traditional use in cobalt sulfate stream purification.

Impurity removal from Co liquor

A Co liquor containing 56 mg/L Zn and 18 mg/L Cd was treated by passing it through a moving bed column filled with AMP resin at a 100:1 ratio (see complete composition in Table 5). The resulting loaded resin was homogenised and used for U-shaped column moving bed desorption. This loaded resin carried 7.8% of the feed Co.

Reviewing the results in Table 5, process performance and benefits are similar to those for the Zn removal from the Ni-Co liquor case. Specifically, low value metal loss with less than 10% Co deportment into the reject stream (equivalent to approximately 0.5% of the feed Co). The impurity circulating load was also minor with less than 5% Cd, and 1% Zn recycled upstream.

Profiling of the U-shaped column at the end of the desorption campaign is presented in Figure 10. In this specific case, Mn played the most crucial role in scrubbing/recovery of Co co-loaded onto the resin, with zinc and cadmium primarily being concentrated in the reject stream.

Table 5: Cd and Zn polishing from Co solution

Parameter	Ca	Cd	Co	Mg	Mn	Zn
Resin loading						
Composition of feed liquor for purification, g/L	0.5	0.018	2.8	0.35	0.615	0.056
Loaded resin, g/L	0.7	1.8	21.7	0.2	12.6	5.6
Upgrade from liquor to loaded resin	1.4	100	7.8	0.6	20	100
Loading as % of feed value metal	--	--	7.8	--	--	--
U-shaped column desorption						
Recycle flow*, BV/BV	1.3					
Reject flow, BV/BV	0.3					
Metal deportment into the recycle stream, %	99	**3**	93	100	**23**	**1**
Metal deportment into the reject stream, %	2	104	6	1	**37**	100
Recycle composition, g/L	0.54	0.04	15	0.13	2.2	0.03
Reject composition, g/L	0.05	7.1	4.8	0.0	17.6	21
Metal balance, %	101	107	98	101	**61**	101

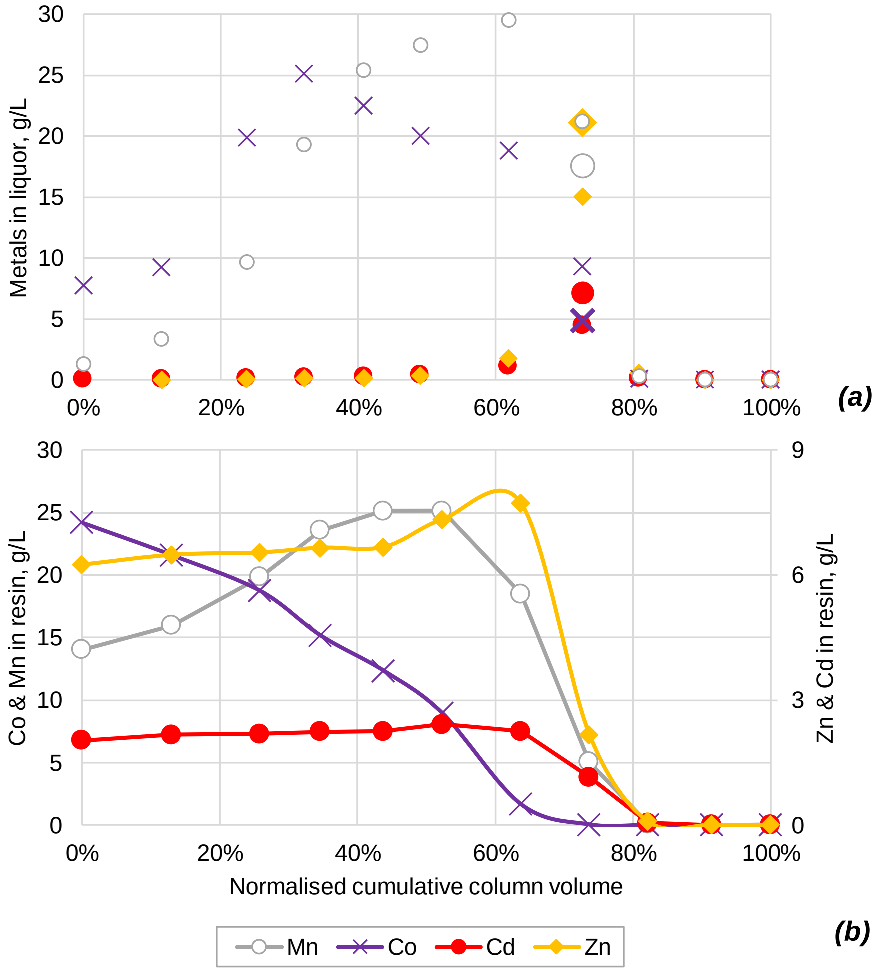

Figure 10 – U-column profile after split desorption of Co from Zn and Cd

CONCLUSIONS

The results from the above laboratory testwork and four pilot campaigns show how the performance of the elution step in typical base metal applications is redefined when changing the elution vessel from a straight fixed or moving bed column to a U-shaped moving bed column.

IDA resin for bulk base metal recovery

The eluate composition, in terms of its value metal concentration, impurity levels, and residual free acid, provides downstream flowsheet flexibility in bulk base metal recovery, with direct feeding to refining circuits, electrowinning, crystallisation all possible. Furthermore, the improved value metal concentration and proportional volume reduction make it feasible to transport eluates to a centralised processing hub. This may allow previously sub-economic satellite deposits or reprocessing opportunities to be brought online.

Apart from flowsheet flexibility, the U-shaped column also benefits capital cost, operating cost and revenue dimensions, as illustrated in Table 6.

Table 6: Project value generated by the U-shaped column in bulk base metal recovery applications

U-shaped column Elution Characteristic	Project Value
Increased eluate concentration due to: - Efficient reagent utilisation allows the use of higher strength eluants, leading to a smaller eluant volume - Rejection of entrained/dilute liquors into the recycle waste	Improves the economics of downstream concentration upgrade and product formation due to reduced hydraulic flow leading to: • Smaller size of downstream circuits (CAPEX saving). • Reduced energy and reagent costs (OPEX saving). Examples: flowsheets where pH adjustment or membrane systems are used downstream. • If precipitation as a recovery option is considered, the residual metal concentrations remaining after product formation represent a smaller recovery loss (revenue benefit).
Decreased eluate free acid concentration due to counter-current flow of eluant and resin	Improves the economics of the IX circuit and downstream circuits: • Less eluant reagent lost from the IX circuit (opex saving in IX). • Less alkali required downstream in metal precipitation processes (opex saving downstream).
Significantly lower concentration of certain impurities in the eluate (e.g. Mg, Ca, Mn)	• Decreases the size of downstream purification processes, such as solvent extraction or polishing IX (CAPEX and OPEX savings)

AMP resin for base metal purification

The use of AMP resin for purification could support similar flowsheet changes to those indicated for bulk recovery (e.g. concentrated liquor recycle to electrowinning; avoid downstream solvent extraction circuits). However, the U-shaped column's key benefit in these AMP resin applications is the sharpness of the value metal – impurity metal split, as outlined in Table 7.

Table 7: Project value generated by the U-shaped column in base metal purification applications

U-shaped column Elution Characteristic	Project Value
Sharper impurity/value metal split	• Less (e.g. 50 – 65% lower) value metal lost to the impurity bleed stream, boosting overall recovery (revenue benefit). • Post-IX treatment may also be enabled (e.g., cementation or SX), permitting value metal return and even higher overall recovery.

	• Reduced (e.g., 90% lower) return of impurities upstream, reducing the overall size of impurity removal step (CAPEX and OPEX saving).

The introduction of U-shaped columns into the base metals processing flowsheets can change the view industry has of ion exchange technology in general. Specifically, enhancement of resin selectivity towards the targeted metal and addressing the water balance issues make the application of ion exchange more viable and attractive.

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