2001 POTENTIAL BENEFITS OF RESIN-IN-PULP FOR PAL PLANTS

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1.0 INTRODUCTION

Recent advances in resin technology have driven a high level of interest in the application of the technology to hydrometallurgical extraction processes.

Currently, the major applications for resin technology are in the uranium and gold industries. Around the world, there are several plants using resins for the recovery of uranium and gold from pulps and leachates.

In Australia, the development of the nickel laterites has provided a tremendous opportunity for the introduction of resin technologies. The hydrometallurgical extraction process beginning with high-pressure acid leach (HPAL) provides an ideal input stream for resin technology with associated advantages.

The current technology schemes for nickel and cobalt extraction from laterites generally involve HPAL followed by counter-current decanter circuits (CCD), precipitation and solvent extraction.

For resin technology to gain acceptance, the advantages offered must be substantial. The advantages that are available to future users of resin technology include:

- High selectivity for target metals
- High separation capabilities
- Flexible processing regimes
- High concentration step
- Simple process design
- Small footprint of plant
- High level of automation

These advantages are seen in

- Lower capital cost of equipment - up to 50% lower cost
- Lower operating costs
- Lower environmental burden - less water consumption and water recycling opportunity

This paper reviews the developments that have occurred in the use of resin technology in the extraction of nickel-cobalt.

2. RESIN TECHNOLOGY

2.1 RESIN TECHNOLOGY IN NICKEL AND COBALT EXTRACTION

2.1.1 Resin Selection

The resin selected for the adsorption of nickel / cobalt from HPAL pulps is Clean TeQ R-604. The 604 resin is a high mechanical strength, macroporous, and chelate-based resin. The resin has been chosen based on its selectivity for nickel and cobalt in the presence of competing ions at the extraction pH.

2.1.2 Method for the Investigation of Adsorption from Pulps

The extraction of nickel and cobalt from HPAL pulps using resin technology is now a technical reality, however the process requires extensive knowledge before a technical scheme is validated and economics are proven.

Clean TeQ has developed a screening methodology that allows resin selection and processing conditions to be determined. The method, known as the "exhaustion method" provides details on the resin selectivity, loading capacity, desorption characteristics, metal recovery and an approximation of the resin to pulp ratio required for commercial schemes.

2.1.3 Direct Resin Sorption from HPAL Pulps

A typical process scheme for the adsorption of nickel and cobalt from a HPAL pulp involves the following process steps:

STEP 1
HPAL pulp received from the autoclave at 90°C and pH 0.3. A typical analysis of the pulp is shown in Table 1.

Table 1 Analysis of Typical Laterite HPAL Pulp

Metal	Metal in Liquid Phase mg/L	Metal in Solid Phase mg/kg
Nickel	4,100	1,200
Cobalt	300	70
Iron 2+	1,200	220,000
Iron 3+	1,200	-
Manganese	1,500	300
Aluminium	1,500	35,000
Magnesium	15,000	18,000
Chromium	20	9,000
Copper	25	35

STEP 2

At pH 0.3, the concentration of iron (ferrous / ferric) in solution is high and will interfere with the adsorption kinetics and loading capacity of the resin.
In order to eliminate interference by soluble iron, the pH of the pulp is adjusted to pH 4, resulting in the iron hydroxide being precipitated. Table 2 shows the result of the analysis of the liquid phase of neutralised pulp.

The nickel concentration in solution has been reduced from 4,100 mg/L to 3,500 mg/L. The nickel has been lost from the solution through co-precipitation with the iron hydroxide. The forces that hold the nickel bound to the hydroxide must be overcome if the nickel is to be recovered. The CCD process is not able to recover this nickel.

Table 2 Typical Analysis of HPAL Pulp after Neutralisation to pH 4

Metal	Metal in Liquid Phase mg/L
Nickel	3,500
Cobalt	270
Iron 2+	125
Iron 3+	<1

STEP 3

Resin (in hydrogen or sodium form) is now added to the pulp, stirred and reacted for appropriate time while monitoring pH and adjusting if necessary. The resin and pulp components are then separated and the loaded resin is stored for later desorption. A sample of the pulp is taken and the solid and liquid phases analysed for nickel and cobalt.

The pulp is then combined with "fresh" resin and the procedure is repeated a number of times (process steps). At each stage the solid and liquid phases of the pulp are analysed and the loaded resins are combined.

The results of the stepwise "exhaustion" process for nickel and cobalt are shown in Table 3 and Table 4 and represented graphically in Graph 1 and Graph 2.

Table 3 Results of Exhaustion Test for Nickel

Stage	Nickel in Liquid Phase mg/L	Nickel in Solid Phase mg/kg
1	450	1200
2	100	1000
3	20	900
4	10	800
5	5	700

Graph1 Nickel Removal in Exhaustion Test

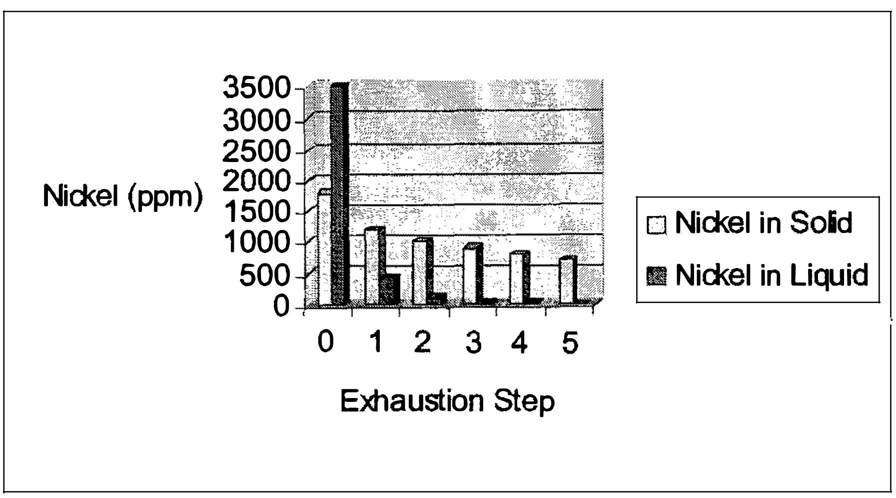
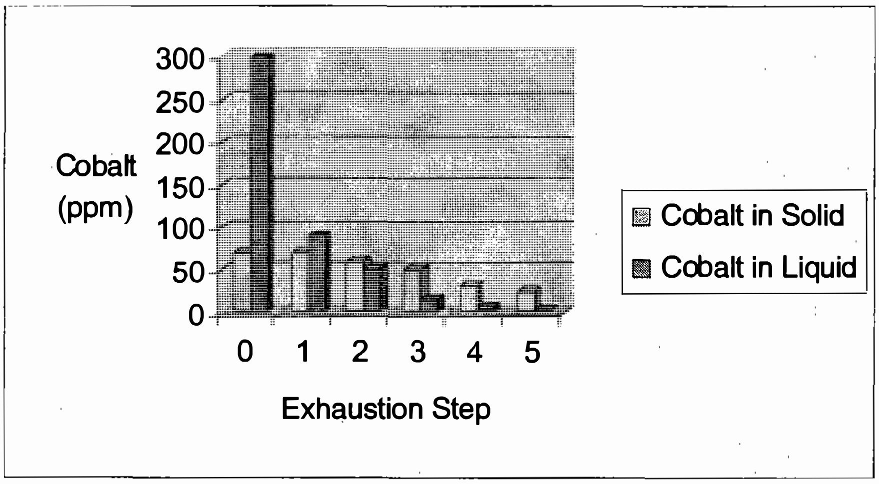


Table 4 Results of "Exhaustion Test" for Cobalt

Resin Adsorption Stage	***Cobalt in Liquid Phase mg/L***	***Cobalt in Solid Phase mg/kg***
1	90	70
2	50	60
3	15	40
4	5	30
5	1	25

Graph 2 Cobalt Removal in Exhaustion Test



The results of the exhaustion test indicated the ability of the resin-in-pulp process to capture the soluble metal values in the pulp and additionally extract nickel and cobalt from the solid fraction of the pulp that would otherwise be lost. Table 5 shows the typical recoveries that are obtained by the resin-in-pulp process acting directly on HPAL pulps.

Table 5 Recovery of Nickel and Cobalt from HPAL Pulp

Source	***Recovery***
Nickel from Pulp Liquid	>99%
Cobalt from Pulp Liquid	>99%
Nickel from Pulp Solid	>40%
Cobalt from Pulp Solid	>60%

STEP 4

The combined resin samples from the exhaustion process are combined, washed with water and desorbed using acid. The pregnant solution obtained from this step was analysed for metal values and the results are shown in Table 6.

Table 6 Metal Concentrations in Pregnant Solution

Metal	Metal in Pregnant Solution mg/L
Nickel	21,000
Cobalt	1,500
Iron	20
Manganese	10
Copper	200
Chromium	1
Zinc	40

The concentration of nickel and cobalt in the pregnant solution is dependent on the initial concentrations of nickel and cobalt in solution. Nickel concentrations of 20 to 30 g/L and cobalt concentrations of 2 to 3 g/L in the pregnant solution are regarded as typical.

Depending on the requirements of the purification circuit, the pregnant solution can then be incorporated directly or further processed by resin technology to separate and obtain a higher purity metal solution.

2.1.5 Resin Sorption from Tailing Pulps

In a similar fashion to that described in 2.1.4, CCD underflow pulps have been subjected to an "exhaustion" scheme. A typical analysis of a CCD underflow pulp is shown in Table 7.

Table 7 Typical Analysis of Tailing Pulp

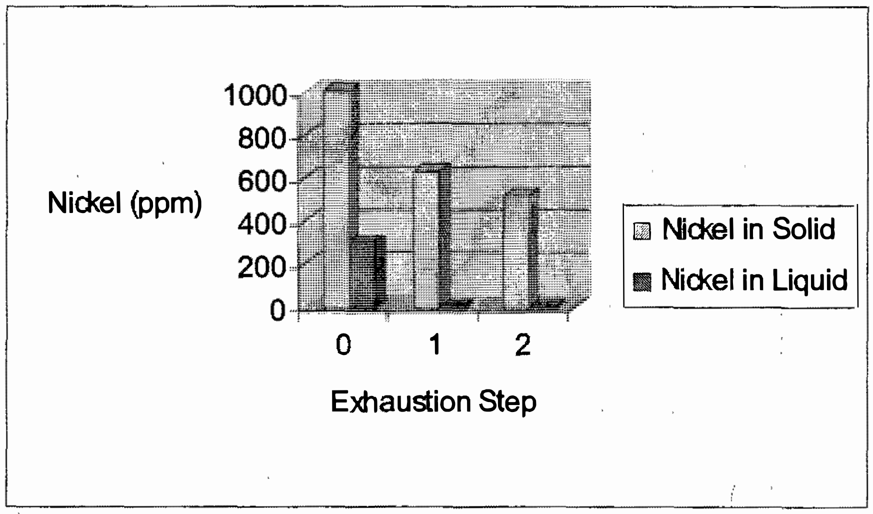
Metal	Metal in Liquid Phase mg/L	Metal in Solid Phase mg/kg
Nickel	300	1000
Cobalt	30	70
Iron	20	210,000
Zinc	1	30
Manganese	900	600
Aluminium	10	16,000
Magnesium	10,500	12,000
Chromium	0.5	4,000
Copper	5	1

The results of a two-step "exhaustion test" for nickel are shown in Table 8 and graphed in Graph 3.

Table 8 Results of "Exhaustion Test" for Nickel

Resin Adsorption Stage	Nickel in Liquid Phase mg/L	Nickel in Solid Phase mg/kg
1	7	700
2	2	500

Graph 3 Nickel Removal in Exhaustion Test



The results again clearly indicate the rapid extraction of nickel from the liquid phase of the pulp. The nickel concentration in the liquid phase is reduced from 300 mg/L to less than 2 mg/L is a two-step process.

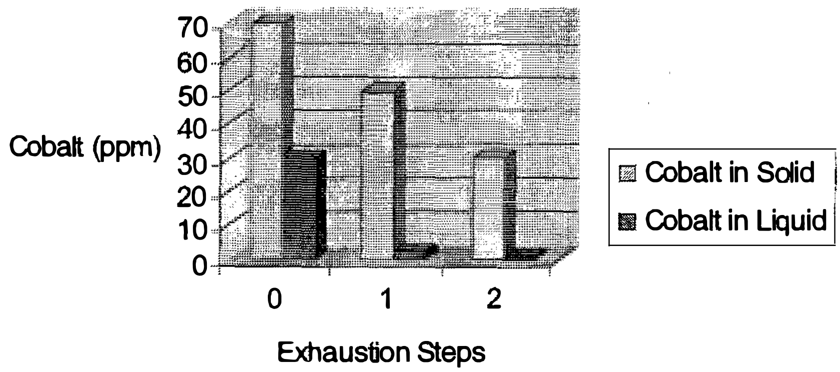
The extraction of nickel from the solid phase is also very apparent, with solid phase nickel being reduced from 1,000 mg/kg to 500 mg/kg in two-steps.

The two-step exhaustion test results for cobalt are shown in Table 9 and graphed in Graph 4.

Table 9 Results of "Exhaustion Test" for Cobalt

Resin Adsorption Stage	Cobalt in Liquid Phase mg/L	Cobalt in Solid Phase mg/kg
1	2.5	50
2	1	30

Graph 4 Cobalt Removal in Exhaustion Test



Cobalt values are recovered from both liquid and solid phases of the pulp in significant quantities.

Again the loaded resins were desorbed with acid solution to provide a pregnant solution. The pregnant solution was analysed and the results are shown in Table 10.

Table 10 Metal Concentrations in Pregnant Solution

Metal	*Metal in Pregnant Solution mg/L*
Nickel	15,000
Cobalt	1,000
Iron	25
Manganese	800
Copper	120
Zinc	7

Again the pregnant solution can be returned to the metal purification circuits. In this instance, however, the pregnant solution contains more manganese than in Sect. 2.1.4. due to the competition between manganese and nickel for the resin. A further purification step would increase the nickel purity if required.

3. COMMERCIAL IMPLICATIONS

Resin-In-Pulp technology can be used to augment current systems or replace conventional technology. In situations where process design is still under consideration, Resin-In-Pulp can be proposed for

- Replacing CCD technology
- Reducing environmental burden

In existing operations where CCD processes are used, Resin-In-Pulp can

- Augment current technology
- Recover wasted metal values
- Upgrade metal purity
- Reduce environmental burden

3.1 HPAL - RESIN-IN-PULP PROCESS

The HPAL process discharges a hot, acidic pulp. The pulp contains dissolved metals including high levels of dissolved iron and manganese. As with conventional technology, the first stage of processing is the neutralisation step to precipitate iron. The pulp, at pH 4, is then sent directly to the Resin-In-Pulp process train.

The Resin-In-Pulp process train would normally consist of ten (10) air-stirred reactors. The reactors are arranged so that the resin and pulp flow in opposite directions (counter-current flow). The design of the reactor and pulp-resin separation system is critical to the operation of the process. As the pulp moves between reactors, some pH adjustment may be required in order to maintain the chemistry for optimum nickel and cobalt adsorption. After passing through the Resin-In-Pulp train, the barren pulp may be neutralised prior to discharge to the tailings dam.

The pregnant resin emerges from the last reactor and is transported to a wash column. The fluidised wash process disengages solids from the resin prior to the resin being transferred to the desorption column. The resin is desorbed using an acid with the desorbed "pregnant solution" transferred for further processing. The desorbed resin is washed to remove residual acid and then transferred to the front end of the airlift reactors.

A major feature of the Resin-In-Pulp technology is the "sorption leach" phenomena. The resin process continuously removes nickel and cobalt from the liquid phase allowing the potential for further leaching. In this way, additional nickel and cobalt is recovered from the pulp that is not normally recoverable by other processes.

3.2 HPAL - CCD- RESIN-IN-PULP PROCESS

Resin-In-Pulp Process can also be applied to the underflow of installed CCD circuits to either increase metal recovery or as part of a process upgrade. The scheme is particularly attractive in situations where laterite ores prove difficult to process in CCD circuits. Difficulties such as long settling times and wash through, resulting in loss of metal values to the tailings, can be overcome with resin-in-pulp technology.

The Resin-In-Pulp Process in these situations would be employed in series with the CCD circuit. In upgrade situations, an opportunity exists for using Resin-In-Pulp in series with high rate CCD circuits. In this case, only 2 - 3 CCD's would be employed followed by the Resin-In-Pulp circuit. The CCD would be used where the process outcomes are commercially attractive, i.e. in the first 2 to 3 CCD's and the resin technology would then be used to recover the remaining available metal values from liquid and solid phases.

3.3 RESIN-IN-PULP DESIGN

The design of the Resin-In-Pulp process is a function of several variables including:
- Hydraulic throughput
- Target metal concentration

The application of Resin-In-Pulp processes is only possible when the properties of the resin, the chemistry and mechanics of the process have been optimised to provide the required outcomes.

In considering each of the variables, some general comments can be made that will govern the economic outcomes.

3.3.1 Hydraulic Throughput

The retention time required for exchange in each reactor is of the order of 0.5 hours. Given the number of reactors will normally be between 7 and 10, this will indicate the size of the reactors and the resulting capital cost of the reactors.

3.3.2 Target Metal Concentration

The sorption and desorption kinetics and the loading characteristics of the resin are governed by the target and competing metal concentrations. Each system design must be calculated from laboratory and pilot tests.

3.4 THE ECONOMICS OF RESIN-IN-PULP PLANTS

The economics of the Resin-In-Pulp Process is governed by:

- Quantity of resin in the circuit
- Power requirements
- Desorption chemical requirements
- Resin loss
- Resin fouling

3.4.1 Quantity of Resin

The resin inventory is governed by the mass load of metal in the adsorption and desorption circuits. The quantity of resin is the base on which the loss factor is calculated and so influences the running costs.

3.4.2 Power Requirements

The power requirements are a function of the hydraulic load, aeration requirements and resin and pulp transfer ratios. The actual dynamics are dependent on pulp density and hydraulics and are detailed at the design stage.

3.4.3 Desorption Requirements

Depending on chemical chosen for desorption, the operating costs will be a function of the resin loading capacity and the chemical used.

3.4.4 Resin Loss

The resin and equipment design is critical to the economics of the process. The resin loss is caused by osmotic shock and mechanical abrasion. The resins have been designed to withstand the high cycling of osmotic pressures that occur in these high rate processes. In the nickel / cobalt case, the osmotic differentials are low due to the process chemistry, whereby the pH differential between adsorption and desorption is only 3 pH units.

The mechanical breakage of the resins is minimised through the equipment design, where the resin mixing and transfer processes are specifically designed to provide less than 20% resin loss per annum. The cost of resin replacement is generally the lowest individual cost item in the running cost of the plant. The major cost centers are chemical costs, power, labour and maintenance.

3.4.5 Resin Fouling

In the Clean TeQ system, resin fouling is checked during the design stage and is not normally a factor.

3.4.6 Basis of Cost of Plant

Table 11 shows a theoretical mass balance and values associated with the operation of a Resin-In-Pulp Plant on the tailings from the underflow of a CCD.

Table 11 Theoretical Resin-In-Pulp Process - Mass Balance

Parameter	Nickel	Cobalt
CCD Underflow output	1,000 m3/h	
Specific Gravity Pulp	1.3	
CCD Underflow Mass Rate	1,300 tonnes/h	
Solid Percent	40%	
Solids Mass Rate	520 tonnes/h	
Metal Concentration In Solid	0.15%	0.02%
Metal Mass Rate	780 kg/h	104 kg/h
Metal recovered by Resin-In-Pulp	60%	50%
	468 kg/h	52 kg/h
Liquid Percent	60%	
Liquid Mass Rate	780 tonnes/h	
Specific Gravity Liquid	1.05	
Metal Concentration In Liquid	200 mg/L	20 mg/L
Metal recovered by RESIN-IN-PULP	95%	95%
	133 kg/h	13 kg/h
Total Metal Recovered by RESIN-IN-PULP	601 kg/h	65 kg/h
Metal Price	$11,000 / tonne	$35,000
Value of Metal recovered by RESIN-IN-PULP	$6,611 / h	$2,275 / h
TOTAL Value of Metal Recovered	$8,886 / h	
Added Value of Metal p.a. (8,000 h)	$71.1 m	

3.4.7 CAPEX & OPEX

The capital and operating costs of the above plant, based on:

- Ten 250 m3 airlift reactors
- 100 m3 resin desorption circuit
- two 50 m3 wash circuits
- 300 m3 resin inventory
- pumping and aeration systems
- control system

has been estimated and is shown in Table 12

Table 12 Typical Opex and Capex of Resin-In-Pulp Plant as outlined in Table 11

Area	Cost
CAPEX	$15 - 20m
OPEX	$0.50 / m3 pulp = $4.0m p.a.

4.0 THE FUTURE

The future of hydrometallurgical processes will be governed by several factors. A major determining step will be the ability of a process to provide financial outcomes in the light of changing ore values, market demand and metal purity.An additional and ever increasing challenge is to lessen environmental burdens associated with resource recovery.

Given that the most of the money is spent in the recovering, grinding, sizing and leaching the ore, it is essential that the extraction and recovery steps are efficient and sustainable from both economic and environmental viewpoints.

In the case of PAL leachates, resin technology is ideally suited to providing increased throughput, recovery and margin improvements. Resin technology offers many advantages that will become apparent to the industry on implementation. The cost structure of processors implementing resin technology will be dramatically altered with returns to shareholder value increasing substantially.

The conservative nature of the industry means that acceptance of the technology may be slow. This will provide a competitive advantage in the short term for technically advanced teams that take the time to understand and implement the technology.

The introduction of resin-in-pulp technology will be more influential in changing the economics of hydrometallurgical extraction than any technical process in the last twenty years.

Diagram 3 Schematic for Resin-In-Pulp Process