THE USE OF SELECTIVE ION EXCHANGE FOR THE RECOVERY OF BASE METALS FROM EFFLUENT STREAMS

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Abstract

Base metal refinery effluent streams may contain low metal concentrations that cannot be recovered by precipitation. Although the concentration is low, the total mass of unrecovered metal can have significant value because of the volumes of effluent generated. This metal may be recovered with high efficiency using selective ion exchange resins.

Three process schemes are considered, *viz.*, fixed bed column ion exchange, continuous countercurrent resin-in pulp, and continuous carousel resin-in-pulp. Each of these has different requirements in terms of equipment, resin inventory, capital and operating costs, and different limitations on feed conditions. Bateman and Mintek recently developed a model which allows an upfront economical evaluation of ion exchange options. The model evaluates the capital and operating costs for each

process scheme for various base metals. This provides a general guideline for selecting the appropriate process arrangement for a given process stream.

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1 INTRODUCTION

Base metal refineries often produce large volumes of effluent containing low concentrations of valuable metals. It is often difficult to assess upfront whether it will be economically viable to invest in the recovery of these metals due to the complexity and high capital cost of the recovery process and/or high operating cost associated with these processes.

Bateman and Mintek recently developed two models, called RC-E (Resin-in-Pulp Costing for Effluent Streams) and RC-SL (Resin-in-Pulp Costing for Solid–Liquid Separation). Both models allow an upfront economic comparison of Resin-in-Pulp *vs*. alternative technologies: RC-E compares various Ion Exchange (IX) technologies for the recovery of metals from effluent streams and RC-LS allows for a comparison of Resin-in-Pulp and solid-liquid separation circuits. The models incorporate both hydrometallurgical data, based on Mintek's testwork and hydrometallurgical database, and costing data, based on Bateman's experience on relevant projects.

In this paper only RC-E (recovery of metals from effluent streams) will be discussed. RC-E was designed for a "quick" evaluation of three IX technologies. Generally, this will allow clients to make an informed decision on whether to proceed with a more in-depth investigation, possibly involving testwork. The benefits of the model are illustrated in this paper, using a theoretical case study, based on the recovery of Co or Cu from a 100 m^3/h effluent stream.

2 ION EXCHANGE TECHNOLOGIES

Two types of ion exchange technologies were considered for the model, namely:

- Fixed bed ion exchange (FBIX), where clarified solution is pumped through resin beds configured in series and/or parallel, and;
- Resin-in-pulp (RIP), where a slurry (solution and solids) is contacted with resin in a stirred tank and resin separated from the slurry *via* screening thereof.

Fixed bed ion exchange is widely used in the water industry and has found application in the metallurgical industry for impurity removal from electrolytes, e.g., Cu from Co at Bulong Nickel in Western Australia and Ni from Co at Chambishi Metals in Zambia. The main advantage of fixed bed ion exchange is that the resin inventory is confined to a single column and hence only subjected to osmotic and/or thermal shock through the introduction of different solutions. The main disadvantage is the degree of clarification required on the IX feed and the control during elution to prevent precipitation of metal species which could result in blockages of the resin bed.

RIP found application in the gold industry and is used as the primary recovery step on most gold plants in the former Soviet Union. The main advantage of resin-in-pulp is that no solid-liquid separation is required prior to the ion exchange step, provided the solid particles are significantly smaller than those of the resin, e.g. solids of 100 micron contacted with resin of around 600 micron. (Pre-screening of grit is required before RIP to prevent oversize particles reporting and recycling with the resin.) In addition, previous work indicated that adsorbed and even precipitated metal losses can be reduced when a strong adsorbent (i.e., resin) is added to the slurry by shifting the solution-solid-resin equilibrium. The main disadvantage of RIP is that resin is subjected to osmotic and thermal shock, as well as physical handling, which could impact on resin losses. Options for RIP circuits include:

- Carousel mode of operation, where the resin stays in the same reactor for the duration of the adsorption cycle and is only transferred for elution. The advantages of this are that resin handling is minimised and the resin inventory more accurately controlled. The disadvantage is that an entire stage has to be drained and screened within a limited period, which adversely affects the capital layout for equipment and resin. At least one adsorption stage, additional to those required to achieve the metal recovery, has to be included for any carousel circuit.
- Continuous mode of operation, where the resin is continuously transferred between adsorption stages and the elution circuit. The disadvantages of this type of circuit are increased resin handling and more difficult resin control. The advantage is that resin is continuously removed from the adsorption circuit, which has a favourable effect on the staging requirement and capital expenditure.

3 THE RC-E MODEL – QUICK ECONOMIC ANALYSIS

3.1 Methodology and Assumptions

3.1.1 Overview

The model consists of three sections; namely:

- Input section
- Results section
- Graphics section

In the Input section, the metallurgical, financial, operational, and environmental data are entered. The model uses these data to do a basic sizing of the equipment for each of the technologies. Up to three different scenarios (different metals, concentration, *etc*.) can be evaluated simultaneously. The sizing data are used for calculating order of magnitude capital and operating costs. Finally, the model predicts cash flows over the project life cycle and calculates indicative Net Present Values (NPV), IRRs (Internal Rate of Return) and Payback. The calculated data are presented numerically in the Results section and graphically in the Graphs section. A report can be printed for both sections.

3.1.2 Cost Estimation

The model aims to give an indication of viability of recovering metals from effluent streams. Order of magnitude costs were therefore deemed acceptable. It should be noted at this point that the cost of specific projects will vary depending on local conditions.

The total capital cost was based on the mechanical equipment cost. From this equipment cost, other project costs (design, instrumentation, piping, electrical, civil) were estimated using factors from Bateman's database of previous project costs.

Mechanical equipment costs are a combination of vendor quotes and Bateman costing database information. A base case scenario was defined and the equipment for this scenario was costed. The costing information for other scenarios is interpolated or extrapolated from this base case scenario using a power law. The coefficients used for the interpolation are equipment specific.

Resin costs were obtained from local vendors. Reagent costs will be project specific and can be modified in the input sheet.

Project life-cycle costing was performed in accordance with standard discounted cash flow techniques. Because the client company weighted average cost of capital (WACC) is not known for the case study, cash flows are not discounted. However, this is built into the model and can be allowed for. Furthermore, a tax rate of 30% and depreciation over five years were assumed for the case study.

With the above as a basis, a spreadsheet model was built that automatically modifies the equipment sizing, capital and operating costs as well as the income generated, to produce a project cash flow. The model also incorporates recent metal prices for copper, cobalt, zinc, and nickel.

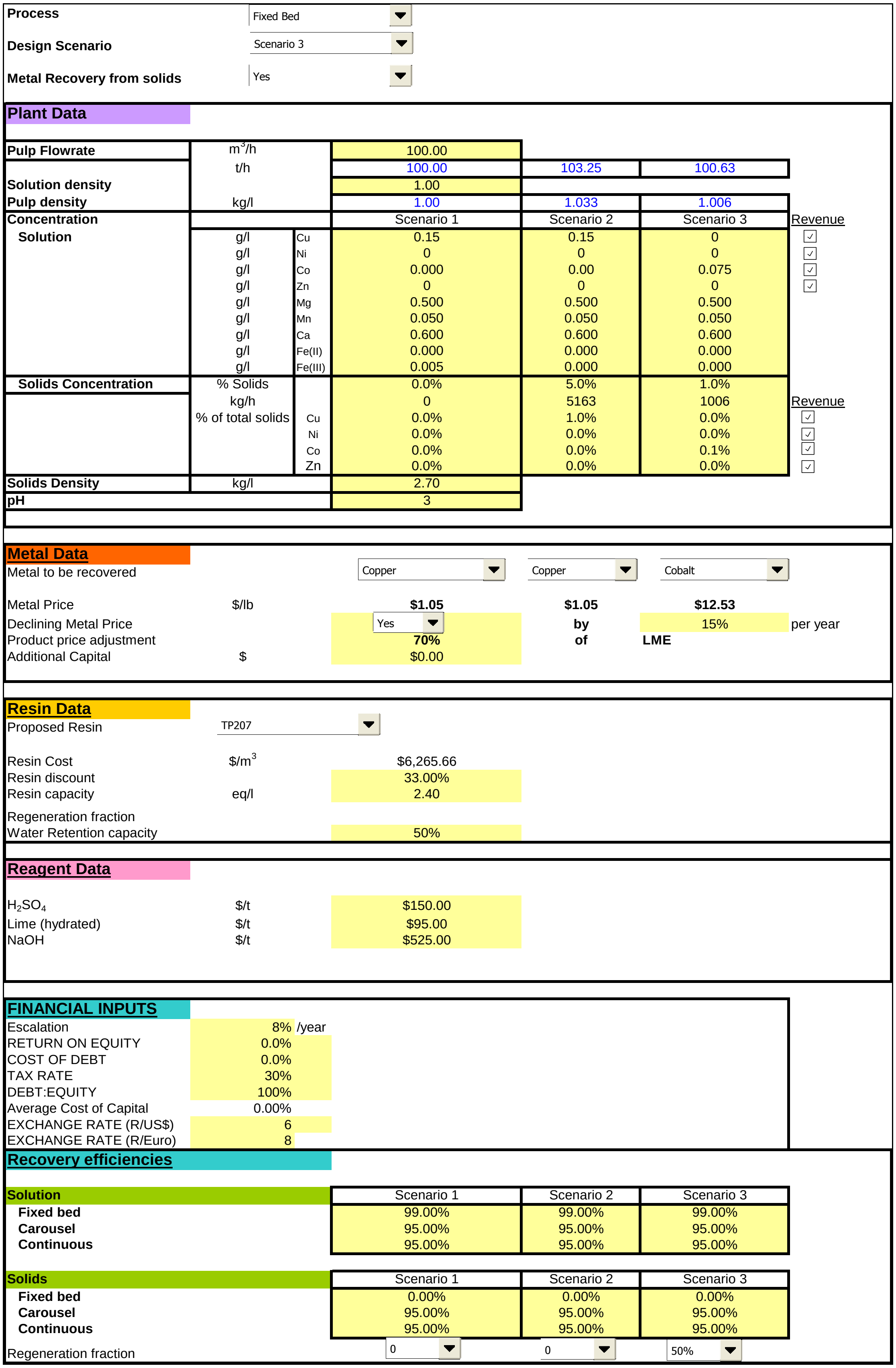
If the final product from the IX process is not a saleable product, but needs additional treatment (e.g., precipitation step or recycling back to existing precipitation), the metal prices can be discounted to reflect the cost of the additional treatment. Additional capital cost for equipment required for the additional treatment can be added.

Specific client requirements, the way the project is structured and financed, tax regulations and the way income is accounted for will all affect the viability of individual projects.

3.2 Input Section

The following input data can be modified, depending on the specifics of the project. Where applicable to the case study, this will be discussed in more detail under "Case Study Results". Where data are unavailable, the model defaults can be used. A typical input sheet is shown in Figure 1.

- Plant Data
  Effluent stream flow rates, densities, analysis (solids and liquid), pH, etc.
- Metal Data
  Metal prices are taken from a database. However, adjustments can be made, to reflect variations in metal price over a period of time (e.g., in the case study a 15% decline in metal prices is assumed).
- Resin Data
  Resin data for three commercially available resins are built in. Selection of the resin is based on experimental data from Mintek.
- Reagent Data
  Reagent prices (e.g. sulphuric acid, lime, etc.) can be adjusted, where required.
- Financial Data
  Financial parameters, such as cost of debt, return on equity, tax rate, etc. can be varied.
- Recovery efficiencies
  If testwork was done and recovery efficiencies (solid and liquid) are available, they can be entered into the model. Alternatively, default values are used.
- Operational Data
  Plant availability can be modified in this section.
- Technology input
  Where various technologies are available, e.g., Pinned Bed Clarifier and polishing filters, a selection of the preferred technology can be made.
- Environmental
  Where (government) incentives are available or a reduction in disposal costs is anticipated, the expected cost saving can be factored into the model.
- Flowsheet Data
  The costing is done based on the equipment in pre-determined flow sheets. However, the option is given to include or exclude feed and effluent tanks and stand-by pumps.



Process	Fixed Bed
Design Scenario	Scenario 3
Metal Recovery from solids	Yes

Plant Data

Pulp Flowrate	m^3/h		100.00			
	t/h		100.00	103.25	100.63	
Solution density			1.00			
Pulp density	kg/l		1.00	1.033	1.006	
Concentration			Scenario 1	Scenario 2	Scenario 3	Revenue
Solution	g/l	Cu	0.15	0.15	0	☑
	g/l	Ni	0	0	0	☑
	g/l	Co	0.000	0.00	0.075	☑
	g/l	Zn	0	0	0	☑
	g/l	Mg	0.500	0.500	0.500	
	g/l	Mn	0.050	0.050	0.050	
	g/l	Ca	0.600	0.600	0.600	
	g/l	Fe(II)	0.000	0.000	0.000	
	g/l	Fe(III)	0.005	0.000	0.000	
Solids Concentration	% Solids		0.0%	5.0%	1.0%	
	kg/h		0	5163	1006	Revenue
	% of total solids	Cu	0.0%	1.0%	0.0%	☑
		Ni	0.0%	0.0%	0.0%	☑
		Co	0.0%	0.0%	0.1%	☑
		Zn	0.0%	0.0%	0.0%	☑
Solids Density	kg/l		2.70			
pH			3			

Metal Data

Metal to be recovered		Copper	Copper	Cobalt	
Metal Price	$/lb	**$1.05**	**$1.05**	**$12.53**	
Declining Metal Price		Yes	**by**	15%	per year
Product price adjustment		**70%**	**of**	**LME**	
Additional Capital	$	$0.00			

Resin Data

Proposed Resin		TP207
Resin Cost	$\$/m^3$	$6,265.66
Resin discount		33.00%
Resin capacity	eq/l	2.40
Regeneration fraction		
Water Retention capacity		50%

Reagent Data

H_2SO_4	$/t	$150.00
Lime (hydrated)	$/t	$95.00
NaOH	$/t	$525.00

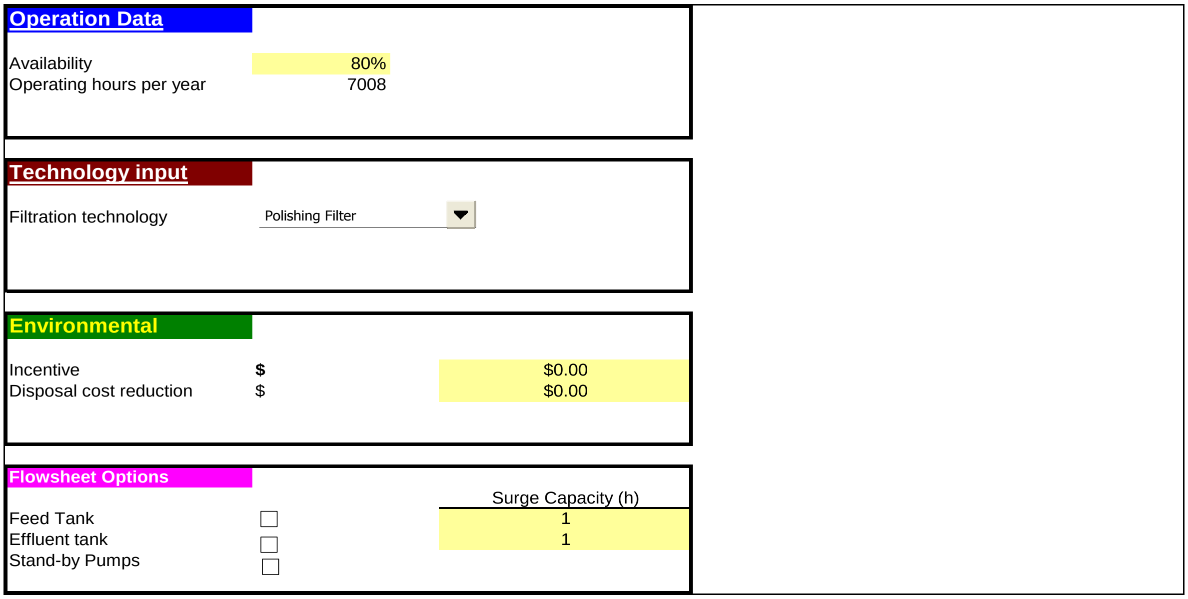
FINANCIAL INPUTS

Escalation	8%	/year
RETURN ON EQUITY	0.0%	
COST OF DEBT	0.0%	
TAX RATE	30%	
DEBT:EQUITY	100%	
Average Cost of Capital	0.00%	
EXCHANGE RATE (R/US$)	6	
EXCHANGE RATE (R/Euro)	8	

Recovery efficiencies

Solution	Scenario 1	Scenario 2	Scenario 3
Fixed bed	99.00%	99.00%	99.00%
Carousel	95.00%	95.00%	95.00%
Continuous	95.00%	95.00%	95.00%

Solids	Scenario 1	Scenario 2	Scenario 3
Fixed bed	0.00%	0.00%	0.00%
Carousel	95.00%	95.00%	95.00%
Continuous	95.00%	95.00%	95.00%
Regeneration fraction	0	0	50%



Operation Data

Availability 80%
Operating hours per year 7008

Technology input

Filtration technology Polishing Filter

Environmental

Incentive $ $0.00
Disposal cost reduction $ $0.00

Flowsheet Options

		Surge Capacity (h)
Feed Tank	☐	1
Effluent tank	☐	1
Stand-by Pumps	☐	

Figure 1 : RC-E Model Input Sheet

3.3 Results Section

Results are displayed in the form of tables. For each scenario, the various IX technologies are evaluated in terms of Total Installed Cost, Resin Inventory, Operating Cost, Total Cost, Income, IRR (internal rate of return over a five-year period), and Payback period.

3.4 Graphics Section

The data from the results section are displayed graphically, to allow a quick comparison between the various technologies and scenarios.

4 CASE STUDY

The case study is presented to illustrate how the RC-E model can be used to provide a quick indication of the viability of potential projects. The recovery of copper or cobalt from some effluent streams was used in the RC-E model and the results are detailed in this paper. Three feeds (Scenarios) were considered and are given in Table 1. Each of these scenarios was then evaluated in the fixed bed, continuous, and carousel RIP models.

Scenario 1 is the base case scenario in which copper is recovered from an effluent stream. In Scenario 2, additional recovery of copper is achieved from solids added to the Scenario 1 effluent stream (this could have been achieved by mixing a residue stream that contains co-precipitated copper hydroxide or adsorbed copper into the original effluent stream). Scenario 3 considers metal recovery from an effluent stream, lower soluble metal concentrations than Scenario 1, and lower solids' concentration than Scenario 2, but the metal recovered is cobalt. All other input parameters are as per the data represented in Table 1.

Table 1 : Feed streams considered for illustration of RC-E model

		Scenario 1	Scenario 2	Scenario 3
Flowrate	m^3/h	100		
Solids' content	mass %	0	5	1
Solution in g/ℓ				
Co		0	0	0.075
Cu		0.15	0.15	0
Mg		0.5		
Mn		0.05		
Ca		0.6		
Solids in %				
Cu		0	1.0	0
Co		0	0	0.1

4.1 Technical Results

4.1.1 Fixed Bed Ion Exchange

Fixed bed ion exchange circuits typically consist of two or more columns in series. A typical operating sequence for a lead-lag-lag (three columns in series) circuit is shown in Figure 2. Solution is fed to the first stage until the resin is loaded. The feed is then re-directed to the second stage, while the first stage is eluted, regenerated (if required), and washed. After washing, Stage 1 comes back on-line in the third position.

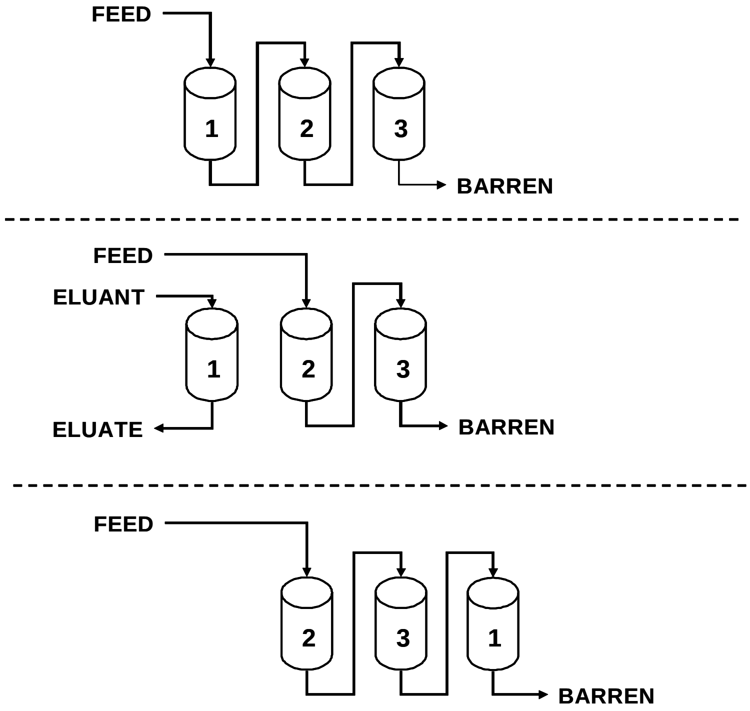


Figure 2 : Operating sequence for lead-lag-lag fixed bed ion exchange

The resin inventory required for a fixed bed ion exchange circuit is determined by the mass transfer zone height to achieve a set effluent concentration from a specific feed, the time required for elution, regeneration, and washing, as well as the upgrading ratio achieved and the number of columns in series. During the design the pressure drop across the resin bed is also considered. The estimated parameters for the fixed bed ion exchange evaluation are listed in Table 2.

The resin selectivity for a given metal is determined by the pH. In order to achieve relatively high levels of Co recovery, the resin is partially regenerated, whilst no regeneration is required for Cu recovery. Details are given in Table 2.

Table 2 : Fixed Bed Ion Exchange Design Parameters

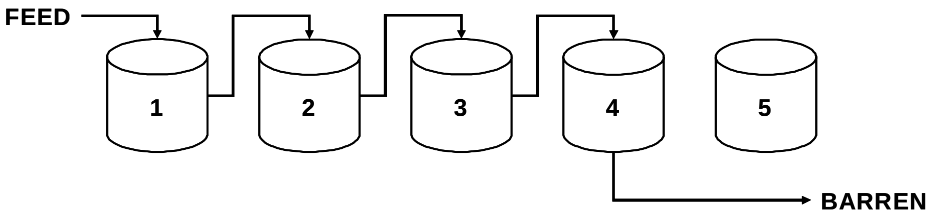
Scenario		Scenario 1	Scenario 2	Scenario 3
Metal recovery from solution	%	99	99	99
Metal recovery from solids	%	0	0	0
Upgrading ratio [a]		400	400	200
Number of columns in series		3	3	3
Regeneration [b]	%	0	0	50
Superficial linear velocity	m/h	20	20	19
Mass transfer zone height	m	5	5	4.7
Elution time	h	4	4	6
Resin inventory	m^3	39	39	42

[a] Resin loading / feed concentration
[b] Degree of regeneration expressed as percentage of capacity loaded with Na^+ ions

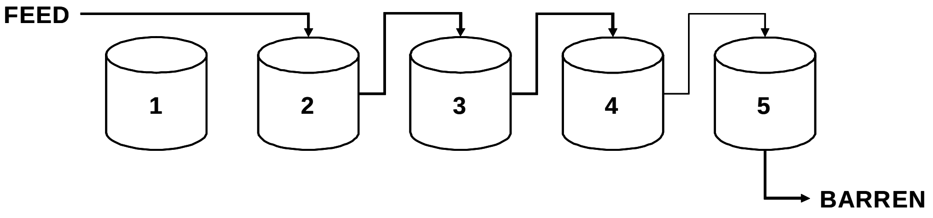
For the purpose of the RC-E model, conservative estimates (based on previous Mintek testwork) are used for column design parameters. However, testwork is recommended to allow for more accurate costing.

4.1.2 Carousel RIP

The carousel RIP circuit consists of a series of stirred tanks. Slurry and resin contact is achieved through mechanically or air agitation. The resin is retained in each stage with screens, while the slurry flows or is pumped to the downstream stage. Once the resin in the first tank is loaded, the feed is re-directed to the second stage, the first stage is drained over a screen to separate loaded resin from the partially metal-depleted slurry, and the slurry is recycled to a feed holding tank or directly to the second stage. At transfer, an extra stage with eluted resin comes on-line at the back of the cascade. Loaded resin is transferred to the elution circuit. After elution and washing, the resin is recycled to the back-end of the adsorption circuit during the subsequent transfer. A schematic of the operating procedure for the circuit is given in Figure 3.



STEP 1 : 4-stages in adsorption, Stage 5 on prepared for subsequent cycle



**STEP 2 : Tank 1 off-line for resin/slurry separation; Feed re-directed to Stage 2;
Tank 5 brought on-line in last position**

Figure 3 : Schematic of the operating procedure for a Carousel RIP operation

The resin residence time in the RIP circuit is determined by the rate of loading (at all times ensuring efficient utilisation of resin capacity), i.e., a minimum contact time would be required to prevent resin from being partially loaded which would result in an increased inventory, faster transfer times, or valuable metal leakage to the barren. However, the transfer time for a carousel circuit depends on the rate at which a tank can be drained and screened, and might be longer than required to achieve resin loading. Hence it might not be possible to design the optimum circuit.

The staging requirement of the circuit depends on the equilibrium profile across the cascade to achieve the desired effluent. The tanks are sized to allow a minimum solution residence time to achieve the desired profile. However, in order to prevent resin-on-resin attrition, the parameters are changed not to exceed a maximum resin concentration. High resin concentrations are required when the system has a low upgrading ratio.

Table 3: Carousel RIP Design Parameters

Scenario		Scenario 1	Scenario 2	Scenario 3
Co/Cu recovery from solution	%	95	95	95
Co/Cu recovery from solids	%	95	95	95
Upgrading ratio [a]	BV	400	400	200
Number of stages in series		4 + 1	4 + 1	4 + 1
Resin residence time per stage	h	3	3	3
Elution time	h	3	3	3
Resin inventory per stage	m^3	0.7	0.7	1.5
Active volume per stage	m^3	28	28	29

[a] Resin loading / feed concentration

As for the column sizing, conservative estimates are used to size the carousel circuit. Testwork is recommended to allow for more accurate costing.

4.1.3 Continuous resin-in-pulp

The continuous resin-in-pulp circuit consists of a series of stirred tanks, as is the case for a carousel circuit. The resin is retained in each stage with screens, while the slurry flows or is pumped to the downstream stage. The resin is transferred counter-current to the slurry through a separate transfer mechanism to minimise resin handling. Resin is continuously transferred from the elution circuit, through the adsorption cascade and back to elution. Transfer time is defined as the average residence time of resin in each stage. A schematic layout of the circuit is given in Figure 4.

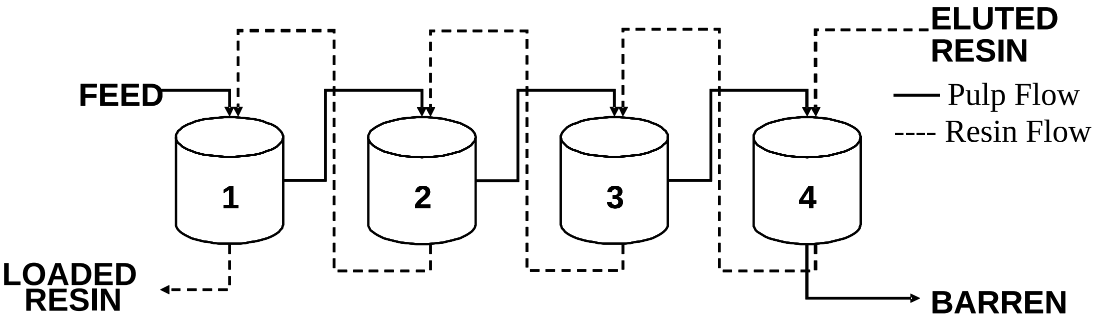


Figure 4 : Continuous RIP operation

The resin residence time in the RIP circuit is determined by the rate of loading (ensuring efficient utilisation of resin capacity), i.e., a minimum contact time would be required to prevent resin from being partially loaded, which would result in an increased inventory, faster transfer times, or leakage to the barren. The mechanism for resin transfer is sized to provide the required resin flow rate.

The staging requirement for the circuit depends on the equilibrium profile across the cascade to achieve the desired effluent. The tanks are sized to allow a minimum solution residence time to achieve the desired profile, without exceeding the maximum resin concentration per stage.

Table 4: Carousel RIP Design Parameters

Scenario		Scenario 1	Scenario 2	Scenario 3
Co/Cu recovery from solution	%	95	95	95
Co/Cu recovery from solids	%	95	95	95
Upgrading ratio [a]		400	400	200
Number of stages in series		4	4	4
Resin residence time per stage	h	2.25	2.25	2.25
Elution time	h	3	3	3
Resin inventory per stage	m^3	0.5	0.5	1.1
Active volume per stage	m^3	26	26	26

[a] Resin loading / feed concentration

Similar test work to that envisaged for the carousel circuit would be required, but both mini- and pilot-plant investigations would be done with continuous transfer of resin.

4.2 Economic Evaluation

4.2.1 Total Installed Cost (excluding first resin fill):

The total installed cost for each process option was determined for the three scenarios discussed above and is represented in Figure 5.

Scenarios 2 and 3 both consider effluent streams containing solids. This implies that for the fixed bed option a clarification step is required. For the purposes of the case study a polishing filter was selected. The additional cost of the filtration step is reflected in the higher capital cost for the fixed bed options. In Scenario 1, no solids are present and the cost for the fixed bed option is more competitive.

The Carousel option is more expensive than the continuous RIP, partly due to the higher complexity in the valving and piping arrangements, but also because an additional stage is required due to the “batch” nature of the process. In some cases this additional cost can be off-set by lower civil costs (no terracing required), but this needs to be assessed on a case-by-case basis, in a more accurate cost estimate study, as the civil costs in the RCE model are factorised.

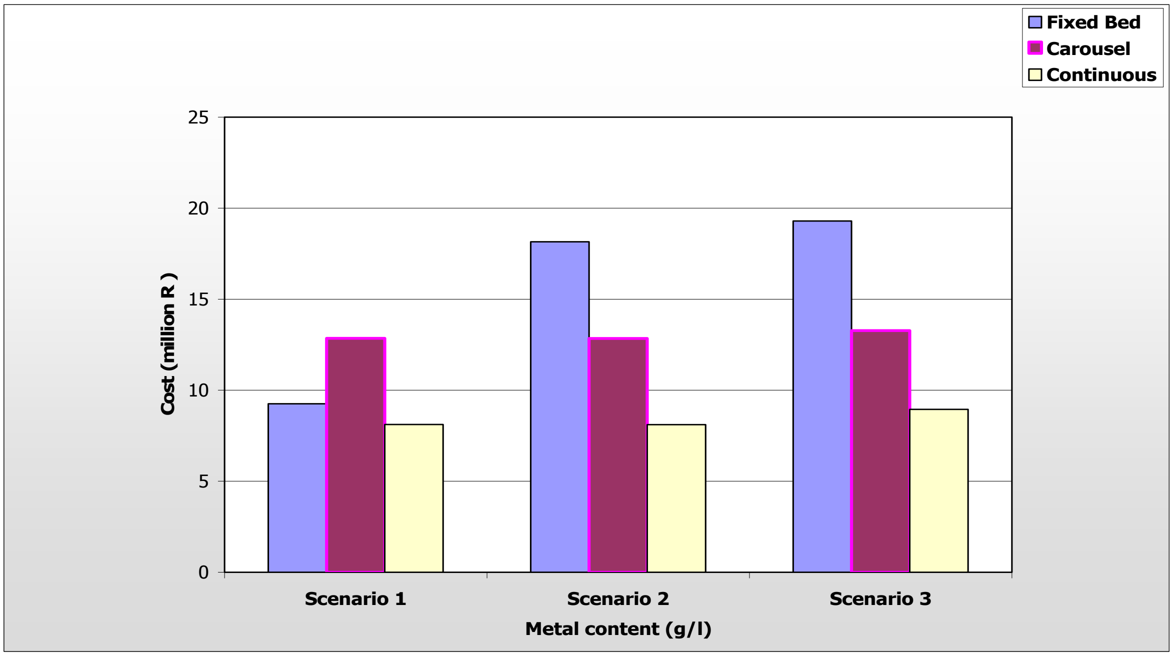


Figure 5 : Total installed cost for Scenarios 1, 2 and 3

4.2.2 Resin Inventory Cost

The "first fill" or total resin inventory required for each process option for the three scenarios was determined and is represented in Figure 6.

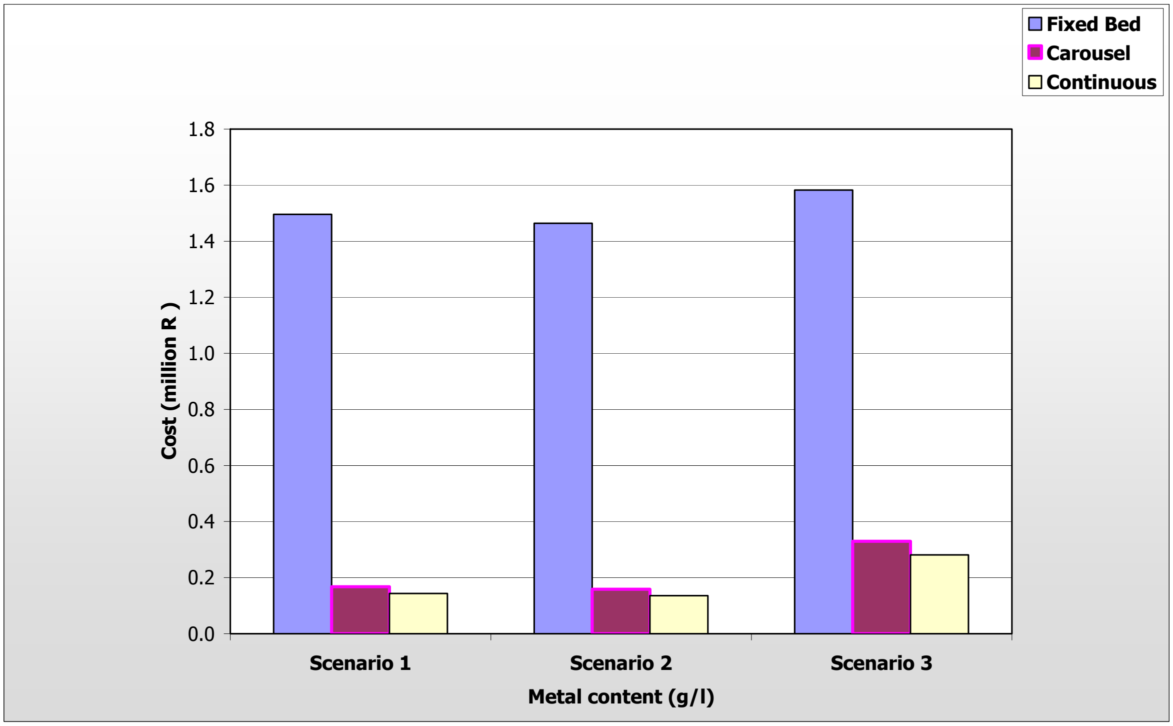


Figure 6: Resin Inventory costs for Scenarios 1, 2 and 3

As explained in Section 4.1, the resin inventory for a fixed bed is calculated on the basis of the required mass transfer zone. In the case study, a metal recovery of 99% was assumed for the fixed bed ion exchange process compared to 95% for the RIP options. If a certain amount of metal "slippage", i.e., higher metal concentration in the barren liquor (or lower recovery) can be tolerated, the resin inventory will reduce significantly for the fixed bed ion exchange process.

Resin inventory for the RIP options is calculated on a mass transfer basis, i.e., the amount of metal that has to be loaded onto the resin at a certain maximum resin loading capacity will determine the resin flow rate.

The resin inventory for the Carousel RIP option is slightly higher than for the Continuous RIP due to a higher resin residence time required.

4.2.3 OPEX

OPEX costs can be split up into two parts: variable costs and fixed costs. The variable costs are those costs associated with reagents and resin losses. Typically, resin losses are higher in the RIP circuits. However, reagent costs can be higher for the fixed bed ion exchange process, if resin regeneration is required (Scenario 3).

For the purposes of this exercise, only maintenance costs (assumed to be 2% of the capital cost for RIP options, 0.5% for the fixed bed ion exchange option) were included in the fixed costs. Although salary costs, building and rental costs, service etc. can be included in the RCE model, they were not taken into consideration for the case study. A comparison of the operating costs estimated for the three different scenarios is given in Figure 7.

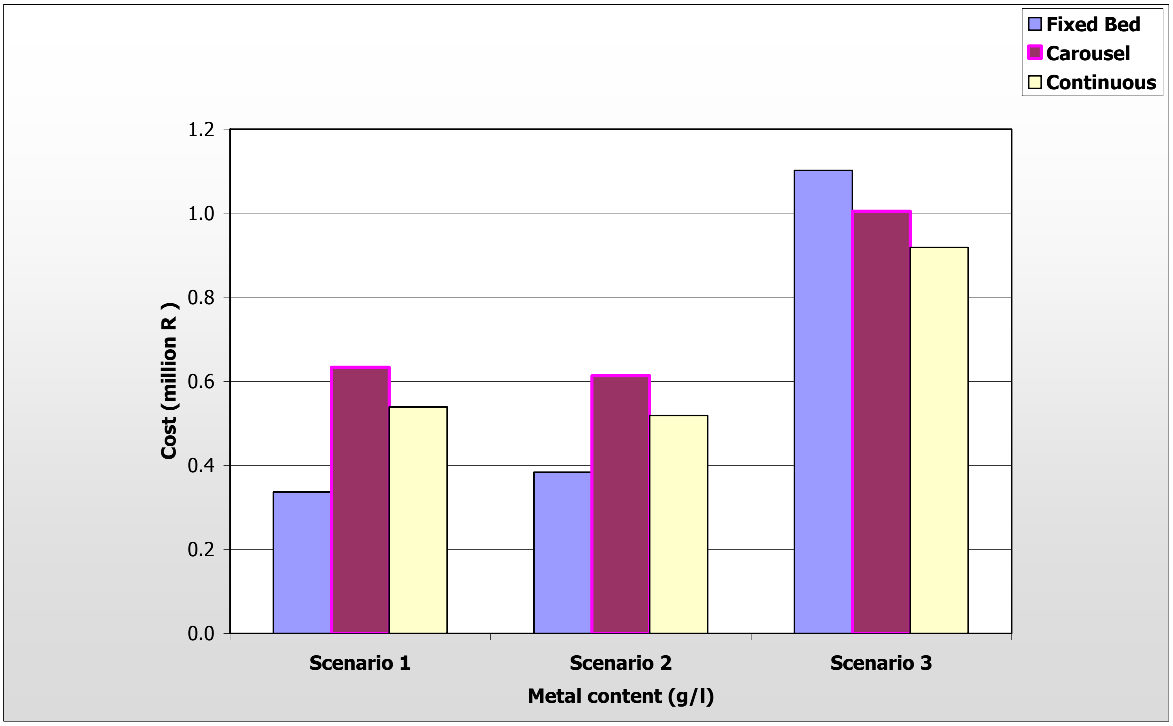


Figure 7: Operational costs for Scenarios 1, 2 and 3

The difference in operating costs between the two RIP processes is due to a higher maintenance cost (as a result of a higher capital cost). Variable costs for the two options are very similar.

4.2.4 Internal Rate of Return (IRR)

The internal rate of return (IRR) and Payback period are indications of the viability of a project. It is not the intention of this paper to discuss the "absolute" viability of the three scenarios (this will be dependant on the various financial factors discussed in section 3.4.1), but rather identify factors which can affect the viability of a project. The IRR was calculated over a five-year period. Where the IRR could not be calculated or was negative, it was not depicted on the graphs. The comparative IRRs for the three different scenarios are shown in Figure 8.

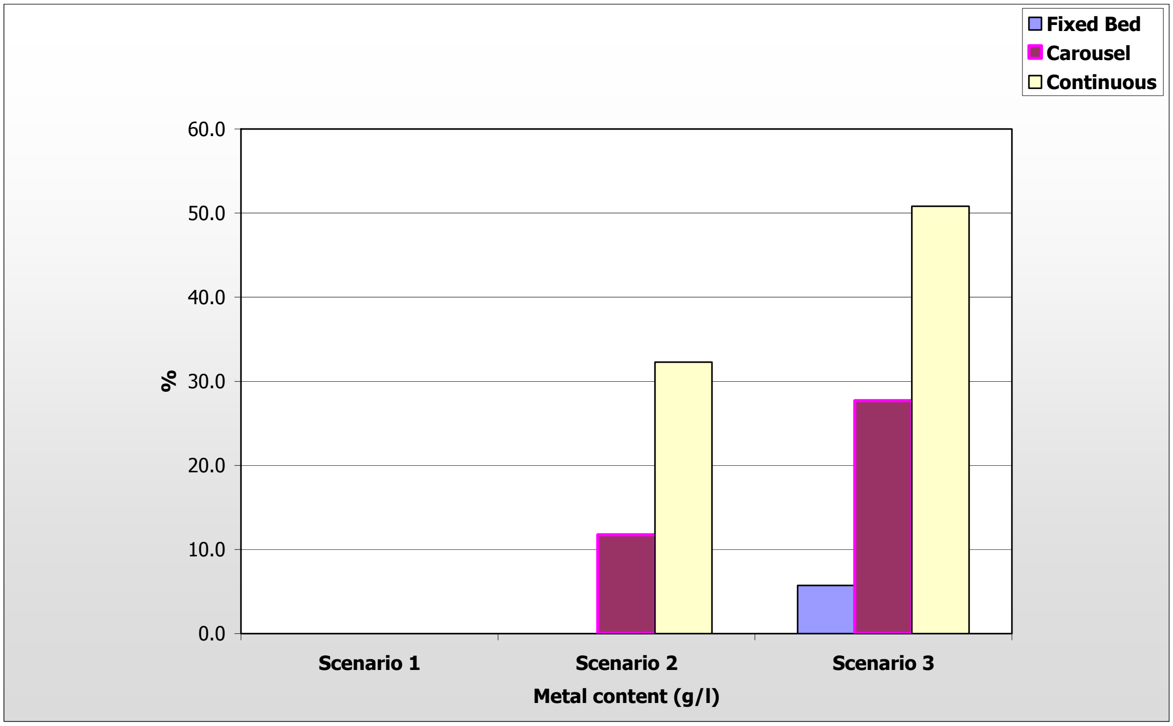


Figure 8: IRR for Scenarios 1,2 and 3

The IRRs for Scenario 1 were all negative over a five-year period. This indicates payback periods of longer than five years (see Figure 10). This would indicate that from an economic point of view, the project is not viable. However, the project might still be viable from an environmental point of view and reduction in disposal costs or government incentives might be possible.

In Scenario 2, the RIP options generate additional income from the recovery of Cu from the solids (see Figure 9). In the fixed bed ion exchange option, no additional recovery is possible as the solids are removed before the ion exchange process. The additional revenue results in a higher IRR and a shorter payback period (Figures 8, 9 and 11).

Although the total metal content is lower in Scenario 3, the IRR is high (and the payback period short) for the RIP options (see Figures 8 and 12), due to the higher cobalt price (more than 10 times the copper price).

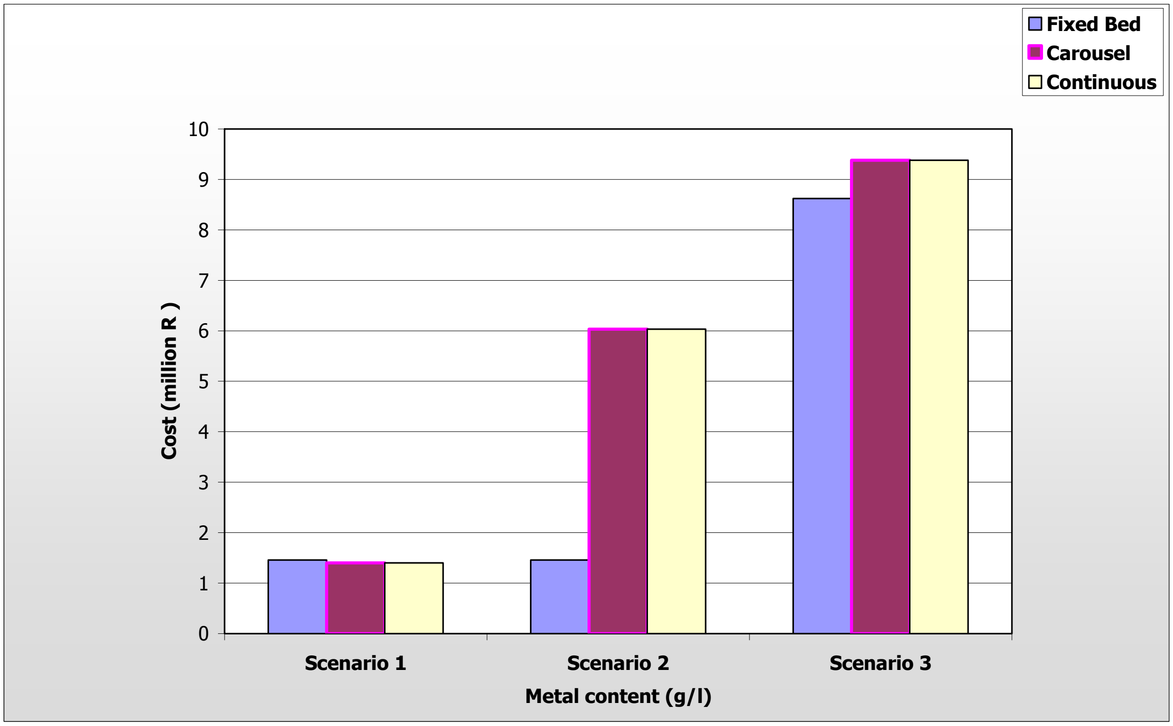


Figure 9: Income generated for the Scenarios 1, 2 and 3

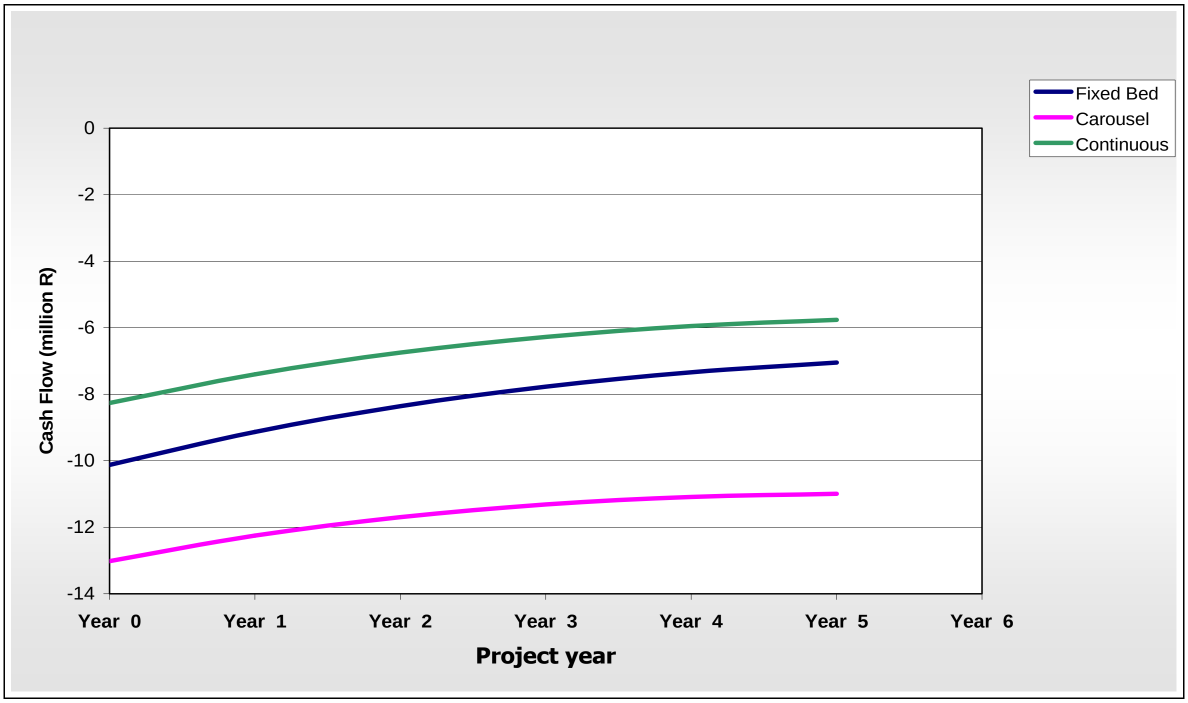


Figure 10: Cash flow for Scenario 1

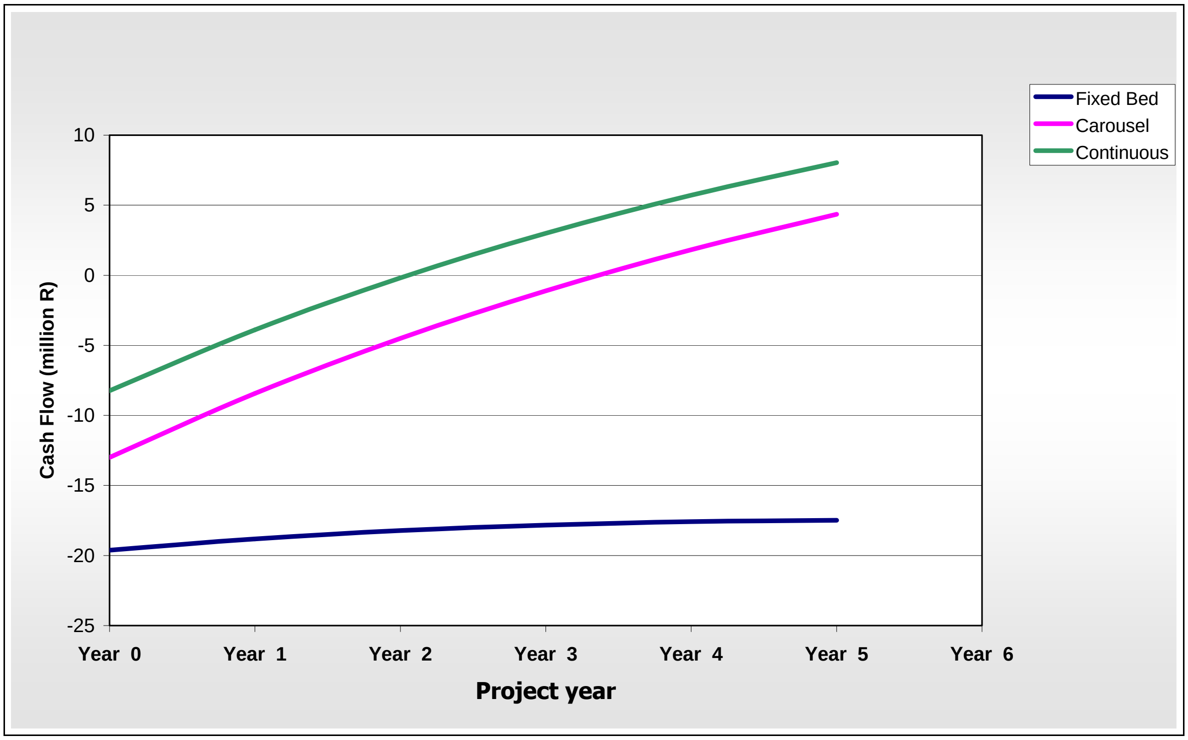


Figure 11: Cash flow for Scenario 2

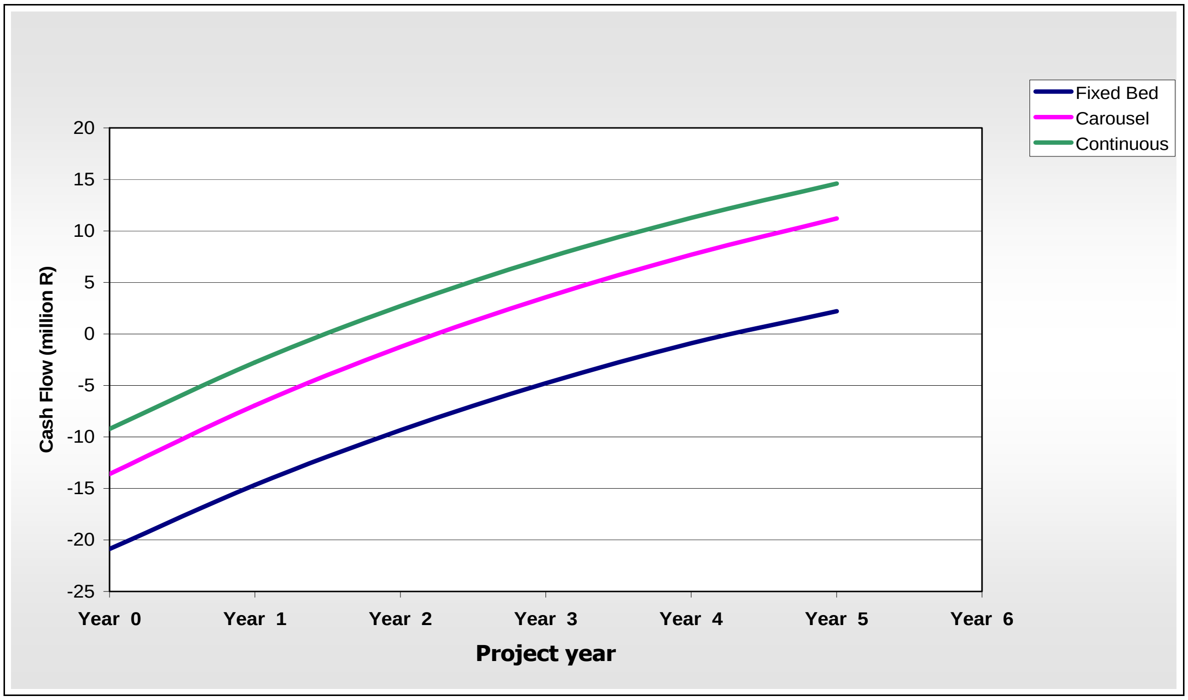


Figure 12: Cash flow for Scenario 3

5 CONCLUSION

The RC-E model gives an indication of the viability of ion exchange processes for the metal recovery from the effluent streams at a very early stage in the project development, prior to any capital expenditure on the project. A sensitivity analysis can be done to evaluate the effect of varying metal prices, blending of effluent streams, variations in recoveries, feed concentrations, etc. or to assist in the identification of the most viable project when multiple projects are being considered.

It is important to understand that the RC-E model only assists in evaluating the viability of a project, and that additional testwork and a more accurate study will be required to design and accurately cost a recovery plant.

ACKNOWLEDGEMENTS

The team would like to thank the following people for their assistance: Mponda Masaninga, Deon Van Tonder and Les Leadbitter.