AN INTEGRATED SYSTEM FOR RECYCLING BASE METAL MINE TAILINGS[1]

by

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Abstract: This paper reports the progress of current research being undertaken at the Royal Melbourne Institute of Technology, Australia, investigating the feasibility of recycling base metal mine tailings. An integrated four-staged recycling system is proposed, involving the retrieval of remnant metals, extraction of potential contaminants, processing for construction materials and backfill, and development of a benign final residue suitable for revegetation and landscaping. The system is designed as both a means of tailings rehabilitation and as an alternative to conventional dam storage. Four case-study mines are used to investigate tailings characteristics and assess the feasibility of the recycling stages. Some of the experimental work for this project is still underway, and economic analyses are incomplete. Nevertheless, results indicate that recycling mine tailings is technically feasible. The system may have only limited application as a means of rehabilitation, but has significant potential as an alternative to conventional tailings management for future mining operations.

Additional Key Words: Leaching, acid mine drainage.

Introduction

Research currently being undertaken at the Royal Melbourne Institute of Technology (RMIT), Australia, in association with the Australian CSIRO[3] Minesite Rehabilitation Research Programme, is investigating the feasibility of recycling base metal mine tailings. An integrated four-staged recycling system is proposed, involving metal retrieval, decontamination, construction materials and backfill, and 'soil' development. The system is designed as both a means of rehabilitation in old and current mines, and as an alternative to conventional dam storage for future mining operations. While cleaner technology research investigates process methods that result in reduced volumes and toxicity levels in tailings, the recycling concept goes further, in removing the need for tailings dams altogether

Mining companies discard a great deal of the material that they process as waste, but it is the contention of this research that tailings should not be viewed as a final waste product, but as part of the resource. Tailings then become an important by-product of metalliferous mining and an asset to be processed and marketed in the same way as the metal concentrate.

Initial studies for this project have included a review of existing technologies and current research, from many different disciplines, that could be adapted and incorporated into the recycling concept. Four case study mines have been used to investigate the characteristics of base metal mine tailings and to assess the feasibility of the four recycling categories. This has included leaching studies, tests on backfill and construction products, and mixing trials for soil development. Some of these tests are still underway. Recycling flowsheets are to be designed for each of the mine case-studies and economic analyses undertaken to assess their recycling potential. The economic viability of the recycling system is being evaluated in comparison with the costs of conventional rehabilitation and potential liabilities, including cost-benefit analysis.

The Recycling System

The recycling system is based on the economic principle that the costs of excavating and transporting the tailings is spread over a number of different processes, all of which are intended to either provide an additional income or a significant cost saving to

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the overall mining operations, as well as eliminating the need for costly tailings rehabilitation. The system involves four integrated stages, namely, retrieving remnant metals, removal of potential contaminants, processing for backfill and various construction materials, and amelioration of the final residue for revegetation and landscaping. While each of these stages are well established concepts, in most cases they are not cost effective in isolation and only become feasible as part of an integrated system. The economic and technical feasibility of recycling is thus dependent upon a continuous flow stream from one stage to the next, without any double-handling or static treatments, and further requires that each process stage is quick, simple and inexpensive.

While the conceptual recycling system is broadly applicable, it has to be adapted to each individual mine site. Site assessment and design of specific flowsheets are therefore required for each operation. Examples of such flowsheets are given in Figure 1. The options and sequencing of the recycling stages are a crucial part of the flowsheet design and are determined by the mining method, metallurgical processes, physical and chemical characteristics of the tailings, mine construction requirements and general environmental considerations. A survey of the whole mining operation, including detailed characterisation of the tailings material, is therefore an essential starting point in establishing the feasibility of recycling and the site-specific process sequencing.

<u>Metal Recovery</u>

Most base metal ores have been concentrated by conventional flotation and any further metal extraction by this method would probably require a costly regrind to increase liberation. Leaching is a relatively inexpensive alternative, and given the low metal grades and small grain size of the material, is probably the most cost-effective means of final recovery from tailings. The continuous extraction of metals and contaminants from mine tailings could be accomplished by a process of slurry leaching, using either a chemical or biochemical lixivient.

Given the scale of most base metal mines it would be both expensive and cumbersome to reprocess all the tailings, and the leaching stage of the recycling system should aim to involve as small and as amenable a proportion of the material as possible. This will normally require some form of pretreatment, such as a total sulphide float or a size separation, to concentrate the leachable metals and contaminants or reduce the quantity of acid-consuming gangue minerals.

There are a number of well established processes for the retrieval of metals and contaminants from leachates, including solvent extraction - electrowin (SX-EW), cementation and precipitation. Much research has been undertaken in recent years into the selective extraction of metals from acid mine drainage (AMD), often through controlled precipitation by regulating the pH of the solutions (Rao and Finch 1992; Kumar et al 1996). This methodology is also readily applicable to extraction from process leachates.

<u>Decontamination</u>

Acidic leaching simulates the natural acid mine drainage conditions that often result in the mobilisation of heavy metals and other potential contaminants. If, therefore, some of the contained toxic elements are not liberated by the leaching stage, it is quite likely that they occur in a stable form and would not constitute an environmental hazard. However, additional processes may be needed and a number of existing and developing decontamination methods are available, including microbial methods, use of ion-exchange materials and adsorption onto immobilised biomass polymeric beads, (Brierley 1993, Mitchell and Atkinson 1991, Bennett and Jeffers 1990).

<u>Backfill and Construction Material</u>

The potential physical uses for mine tailings are numerous, primarily as a fill material and in construction. The greatest proportion of the total tailings volume is likely to be processed and utilised in this section of the recycling system.

Underground mine backfill has traditionally used only the coarse fraction of process tailings because of the inherent problems of drainage and stability with fines. It may therefore be appropriate to separate the tailings into size fractions suitable for backfill and the finer material for block or brick construction. However, there has been considerable work in recent years into using 'total-tails' for backfill (Cory 1996); paste-fill; and other studies into the use of agglomerated fines, where stabilised pellets are used for aggregate (Amaratunga 1991).

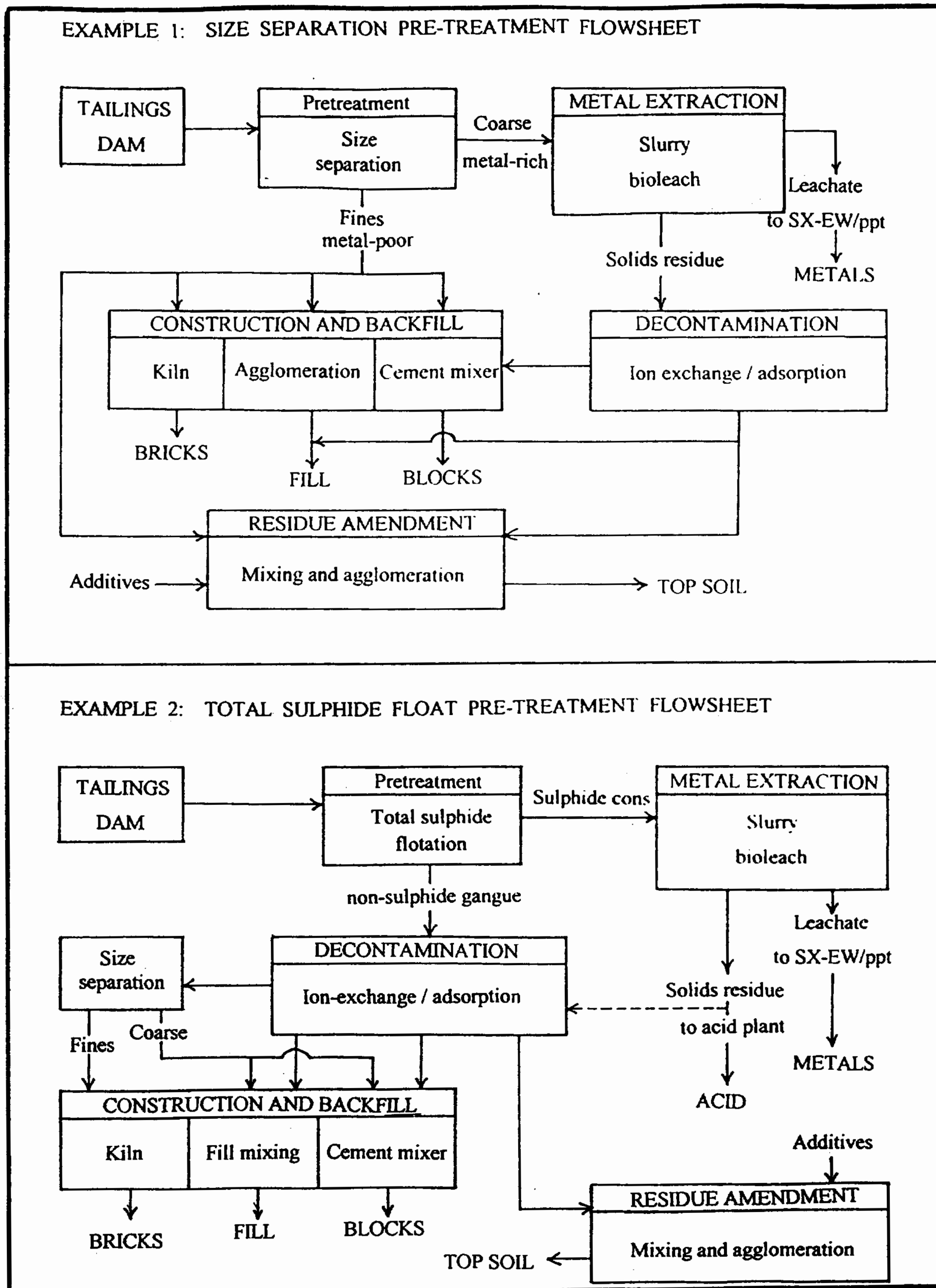

Figure 1. Examples of Tailings Recycling Flowsheets

In any mining operation there are numerous requirements for construction materials such as bricks and concrete blocks, both on surface and underground, and the cost savings of producing these on-site with readily available materials can be significant. Some of these applications require long-term stability and high strength, while others require only a short-term load-bearing capacity. A number of recent research projects have investigated the potential of manufacturing blocks from mine tailings, and have shown that the resulting products can be superior to commercial concrete blocks in terms of both strength and durability (Trinity-Stevens 1995).

Provided that most of the potentially mobile metals and contaminants have first been removed, then mine tailings can be used for almost any form of infilling or covering around the mine site. Fines can be used as a low permeability cover for reactive mine rock waste, and 'cemented' tailings may be used to infill final voids in open-cut operations.

The chemical content and stability of fill and construction materials manufactured from mine tailings can pose environmental and safety concerns. While it is envisaged that decontaminated tailings would generally be used for these applications, it is important to demonstrate the leach resistance of such products. If backfill materials and brick and block products can be rendered chemically inert by the manufacturing process, then contamination can be avoided. Furthermore, if the processing methods can be shown to effectively 'seal' potential contaminants within the material, either by physical encapsulation, or by chemical stabilisation, this may offer an alternative means of pollution control.

Amelioration of Final Residue

Tailings are not generally amenable to revegetation in their raw state. They usually contain high levels of heavy metals and other plant toxins, have very little in the way of macro-nutrients or organic content, and have a poor structure.

Nevertheless, mine tailings have a high potential as a growth media. By taking a raw, undisturbed rock material and breaking it down to soil particle size, mining has simply accelerated part of the natural soil forming process, with the advantage that none of the essential trace elements are likely to have been leached away, as is often the case during natural soil development. Tailings, therefore, present a good starting material for the creation of a fertile growth medium.

Assuming that the metal extraction and decontamination processes have sufficiently removed plant toxins from the tailings, the free-flowing material requires only the addition of deficient plant nutrients, organic matter and microbial elements, and an improvement of the physical structure. These amendments can be achieved in a single-stage process, through the addition of a pre-composed soil enhancing 'brew' made of readily available resources such as sewage sludge, flyash and compost (Sopper and McMahon 1988), and a specifically designed method of mixing. With the process of mixing and binding a form of agglomeration is achieved, and a 'soil' texture developed that has good grain stability, void ratio, and compaction and permeability properties (Hunter and Whitemen, 1975). There may also be some potential to add a seed base with the soil amendment mixture, or specifically isolated rhizobium strains that can symbiotically partner suitable nitrogen fixing legumes, to aid subsequent revegetation (Aswath et al 1995).

The end product would be suitable for a number of site applications, including landscaping and revegetating mine spoils and other degraded areas, and generally improving the visual quality of the mine site. By developing a cohesive structure and establishing a self-sustaining vegetation cover, the created landforms will have good slope stability and increased resistance to water and wind erosion.

Recycling Research

Four case study mine sites were selected from around Australia to assess the feasibility of recycling and to demonstrate the data collection requirements for site evaluation and design of flowsheets. Tailings samples were collected from each of the mine sites and detailed characterisation studies undertaken to provide data on both physical and chemical properties, mineralogy, acid-base accounting and microbiology.

Column experiments were established to demonstrate the leaching potential of each of the mine tailings, to study the natural geochemical reactions occurring under oxidising conditions with a control water flush, and to test an acidic leaching/bioleaching system. Pre-leach concentration methods to improve the amenability of these tailings to leaching for metal extraction are also being assessed.

Considerable research has been undertaken in the field of backfill materials, production and testing, and it is not within the scope of this project to attempt any unique experimentation. Nevertheless, some evaluation of the specific case-study tailings within the context of the recycling system was necessary. Subsequently, various additives and a range of mixes using tailings from each case study have been tested for physical and strength properties.

Similarly, a number of batch mixes for block construction have also been assessed, testing different proportions of slag, lime, cement and flyash. Brick making is being investigated in association with several commercial brick manufacturers. This includes dried 'mudbrick' technology and kilned refractory brick methods.

Research into soil development includes the study of different potential additives, and the methods of mixing to improve the structure. This includes chemical, physical and biological analyses of the materials, together with an assessment of their natural coagulating and binding properties. Mixing methods, primarily utilising a continuous-feed rotating drum system, are being tested, where the tailings and additives are agglomerated together.

Case-Study Mine Sites Characterisation Studies

The four case-study mine sites selected for this programme were chosen to provide a wide range of base metal mine types, covering various geological and topographic environments, climatic regimes and different ore targets. They include Mount Isa Mines, McArthur River Mine, Leinster Nickel Operations and Pasminco's Rosebery mine. Locations of these mines are given in Figure 2.

Mount Isa Mine (MIM) is located in northwest Queensland. It has a hot, semi-arid to arid climate, and a relief of rocky ridges in generally undulating terrain. The mine targets two deposits: large, primary disseminated copper ore; and banded lead-zinc-silver mineralisation. It is a large-scale operation using open stoping with cemented backfill in the copper orebodies and a combination of sublevel open stoping, cut-and-fill and benching methods in the lead-zinc-silver ore. Processing is by conventional flotation with a heavy medium separation in the lead-zinc circuit. Mixed tailings from both copper and lead-zinc streams are cycloned to produce sand for backfill and the residue is thickened and deposited in dammed valley impoundments.

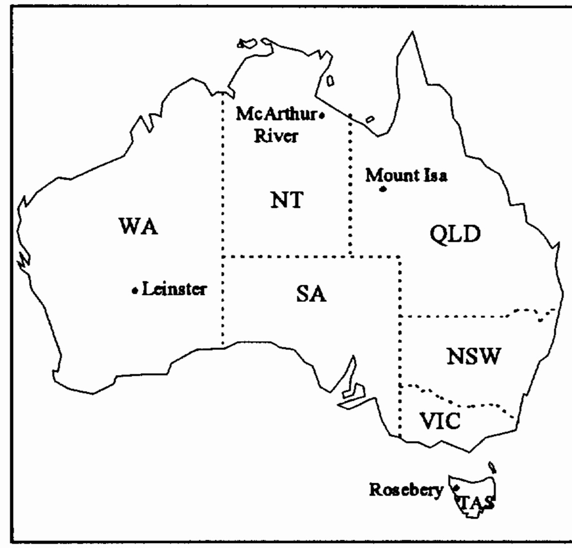

Figure 2: Locations of Case Study Mines

The Perseverance and Rocky's Reward mines at Leinster (LNO), in central Western Australia, are in a hot, semi-arid climate and an area of low relief. The mines target both disseminated and massive nickel sulphide orebodies in a high-grade metamorphic komatiite/serpentinite host rock. Initial open-cut operations are now superseded by underground mining, using both panel stoping and sublevel caving methods. Mixed tailings from both mining operations are deposited as a slurry via perimeter spigotting into a rectangular constructed impoundment with four bays for cyclical deposition.

The McArthur River operation (MRM) is located in the northeast of the Northern Territory. It has a hot, generally dry climate with some monsoonal influence. The area has an undulating relief with low hills and creek beds. The orebody is one of the largest sediment-hosted stratiform sulphide deposits known, containing very fine-grained lead-zinc-silver ore. While still in the early stages of production, the operation will use underground room and pillar methods with some floor benching. A very fine grind is required to liberate the ore prior to conventional flotation. Tailings are thickened before being pumped to a circular impoundment utilizing a natural topographic depression with some perimeter embankments. Deposition is by a modified central discharge system.

Pasminco's Rosebery mine (PRM) is in northwestern Tasmania, in an area of rugged mountainous relief, and a cool, wet temperate climate. The orebody is a polymetallic, massive stratabound deposit with lead, zinc, copper, silver and gold all recovered in the mining operation. There is a long history of mining at Rosebery, but currently, underground mining is by sublevel open stoping methods with some mechanised cut and fill. Tailings are pretreated with lime to raise the pH to around 10, and are then piped to a dammed valley impoundment.

Sampling. Representative tailings samples were collected from each of the mine sites. Sampling methods ranged from a comprehensive drilling programme totalling 1120ft.(343m) at Mount Isa; hand-augering at Leinster and Rosebery, generally to not more than 8 ft.(2.5m) depth; and basic spade collection from locations around the edge of very fresh tailings at McArthur River (milling started May 1995). The level of confidence in these samples being representative of the whole tailings varies accordingly, and is lowest for the McArthur River material. Detailed characterisation studies were subsequently undertaken on these tailings samples.

Physical Properties. Physical studies of the tailings included moisture contents of individual samples, together with measured and calculated specific gravities, and bulk and dry densities. Size distributions have been obtained using sieve and cyclosizing, and for the Mount Isa material, a laser-particle analyser. Average sizings are given in Table 1, which shows that all of the case study tailings are relatively fine grained. The McArthur River tailings material is notably finer than the others and the particle size range is significantly higher in the Rosebery material.

Where possible, geotechnical tube samples were also collected and subsequently used for triaxial and consolidation tests. Both Rosebery and Leinster tailings behave like silt, with low strength and virtually no cohesion, whereas the higher proportion of fines in the Mount Isa and McArthur River materials improves cohesion.

Chemical Properties. Chemical assaying was undertaken on splits of each sample and on the different size fractions, analysing for target metals, sulphur, iron, and major gangue elements. In addition, both fusion and pressed powder X-Ray Fluorescence (XRF) methods were used for total chemical analysis of composites from each mine site. Table 2 shows the average chemical composition of each of the case-study materials.

Metal values are low, except for the McArthur River samples, which were collected less than 6 months after mill start-up and are not representative of the long-term tailings composition. Gangue elements reflect the host rock mineralogy, with significant Ca and Mg from dolomite in the MIM samples, and Mg from lizardite (a serpentine mineral - $Mg_3(Si_2O_5)(OH)_4$) in Leinster material. Other potentially toxic elements such as As, Cd, Se and U are less than average crustal abundances in all the case studies apart from the volcanogenic Rosebery material.

Mineralogy. An initial survey of Company geology and mineralogical reports was followed by X-Ray Diffraction (XRD) analyses on either individual or composite tailings samples. Microscopic studies using both reflected and transmitted light were undertaken to ascertain mineral associations and locking, grain shapes, textures, and the degree of alteration and leaching. The average modal abundances of the main mineral constituents of each case-study material is given in Table 3.

Typically, gangue sulphides are major constituents in all of the samples, with pyrrhotite accounting for 17% in the Leinster material and pyrite between 7% and 20% in the other mine samples. Acid consuming minerals are notably absent from the Rosebery tailings, but 18% dolomite in the MIM material and the high level of lizardite in the LNO samples are major acid buffering components.

Acid-base accounting. A number of procedures were carried out on the samples to determine the acid-base characteristics of the different tailings materials. These included measuring pH and electrical conductivity, and using total sulphur contents to calculate maximum acid production. Acid neutralisation capacity (ANC) was determined by the method of Sobek (Hutchinson and Ellison 1992), with subsequent calculation of net acid producing potential (NAPP) (Miller *et al* 1991), and net acid generation tests (NAG) carried out. Results of acid-base accounting tests are given in Table 4. These tests show that Mount Isa tailings are persistently alkaline and that the Leinster material is generally neutral and

Table 1. Tailings Particle Size Distribution (%).

	105 um	75 um	53 um	38um	-38um	8um	-8um
MIM	13.80	7.01	7.79	8.94	62.47	33.67	28.80
MRM	-	-	-	22.36	77.64	52.37	25.27
LNO	-	21.23	13.26	11.25	54.27	26.46	27.81
PRM	23.33	14.61	15.22	12.53	34.21	-	-

Table 2. Chemical Composition (XRF)

Assay	MIM	MRM	LNO	PRM
Cu %	0.12	0.17*	0.03	0.09
Pb %	0.29	3.4*	<0.01	0.41
Zn %	0.41	6.20*	<0.01	1.21
Ni %	<0.01	<0.01	0.66	<0.01
Co ppm	127	34	129	9
Ag ppm	12	44*	<0.01	26
Au ppm	<0.1	<0.02	<0.01	0.6
Fe_2O_3 %	12.40	12.03	20.19	18.66
S %	3.47	8.99	4.26	9.35
SiO_2 %	40.52	32.59	36.27	45.72
CaO %	11.37	5.74	1.76	1.18
MgO %	6.78	3.84	18.78	1.51
Al_2O_3 %	3.84	7.08	3.51	8.67

(* Note: McArthur River samples are not representative of tailings composition.)

Table 3. Tailings Mineralogy % (XRD)

Mineral	MIM	MRM	LNO	PRM
Quartz	36	30	20	35
Dolomite	18	10	3	-
Lizardite	-	-	22	-
Pyrite	7	15	4	20
Pyrrhotite	2	-	17	1
Feldspars	3	10	5	1
Chlorite	3	2	6	3
Amphiboles	-	-	6	1
Micas	4	5	2	3
Carbonates	3	3	5	4
Oxides	8	10	2	8

Table 4. Acid-Base Accounting Data

Mine	pH (slurry)	EC uS/cm	ANC kgH_2SO_4/t	Sulphur %	NAPP kgH_2SO_4/t	NAG Final pH	NAG kgH_2SO_4/t
MIM	8.57	3,400	362.6	3.47	-256.4	8.19	None
MRM	7.03	4,700	179.5	8.99	95.8	6.42	11.76
LNO	7.49	13,200	310.8	4.26	-180.4	4.40	9.8
PRM	6.98	7,300	55.79	9.35	230.3	2.71	39.2

MIM-Mount Isa Mines, MRM-McArthur River, LNO-Leinster Nickel, PRM-Pasminco Rosebery Mine.

unlikely to become acidic even in the long term However, both McArthur River and Rosebery tailings are potentially acid generating, with Rosebery exhibiting the most acidic tendency.

Microbiology. Basic microbiological tests were carried out on fresh samples of tailings, including most probable number (MPN) of sulphur-oxidising bacteria, a modified buried slide technique (Sobek *et al* 1978), and comparative reaction rate tests. Results of these studies have so far proved inconclusive, and may not be reliable given the possibility of contamination during testing. The MPN count from the sulphur-oxidising bacteria cultures indicate a population of over 6000 bacteria per ml of tailings solution for both Mount Isa and Rosebery and approximately 600 for Leinster and McArthur River. However, other observations show little evidence of an active bacterial presence.

Leaching Studies

Column experiments were established to observe the geochemical behaviour and to demonstrate the leaching potential of each of the case-study tailings. These column tests have run for between 12 and 18 months. Data was collected on pH, Eh and chemical contents of column discharges, and observations recorded on flow paths and extent of fluid/mineral contact.

Experimental. Two columns for each case-study mine were set up, one as a control water flush to study the natural geochemical reactions occurring under oxidising conditions, and the second to test the acid leaching system. Clear perspex columns, 6 in (15cm) diameter and 5ft.10in (1.8 m) high, were loaded with a 1:1 ratio mix of whole dry tailings and crushed quartz (to maintain permeability). Charging of the columns was designed and implemented to avoid any compaction other than natural settling and progressive weight loading.

The control columns were flushed with aerated deionised water, while the acid leaching columns were initially run in recycling mode, the discharge being collected, modified, and returned to the feed container. After a build-up of excessive solute concentrations, this feed system was changed to a once-through acidic flush, using an aerated sulphuric acid solution, starting at pH 3.0 and subsequently at pH 1.8. The application rate of the feed liquids was kept low, at around 2ml/minute, to provide continuous wetting without flooding, and allow air (and therefore oxygen) to penetrate the material in each column. Data was collected three times a week on room temperature; inflow rates; pH, Eh and EC of discharge solutions; and the volume of discharge from each column. Once a week a filtered leachate sample was taken from each column and sent for ICP-AES analysis.

Physical Results In all columns, the wetting front was uneven, but not lobate, suggesting a fairly regular distribution of grain sizes, and a good mix of tailings with the quartz filler. It took between 44 and 60 hours from the start of application for the liquids to break through the base of the tailings, and used between 6.30 L and 9.12 L of liquid to wet all the material. There was a 3-8in (7-20 cm) drop in the height of material in the columns from dry to wet state, representing volume decreases of between 6 and 14 percent. All of these observations correlate well with the known physical characteristics of the individual tailings, especially those of grain size distribution, SG and density. There was little obvious migration of fines down through the columns, nor any further volume change since the material was saturated.

Permeabilities through the material have been generally good, with the exception of one of the Mount Isa columns, which persistently backed up and had to run at half the normal flowrate. Outflow rates have been consistently equal to inflow. The liquids have flowed evenly through the tailings with no preferred flowpaths, and the leachate/mineral contact was good. There was, however, a much more erratic pattern of oxygen/mineral contact, with distinctive oxidation haloes around more compacted zones. While there are distinct physical differences between the case-study columns, there is almost none between the water flush and the acid columns, suggesting that the physical behaviour of the material is not effected by the nature of the percolating fluids.

Eh, EC and pH. Even with the ideal oxidising conditions designed for the columns, there has been limited acid generation from these tailings materials. The pH of the water flush columns generally remained around neutral to alkaline, with Mount Isa and Leinster discharges consistently above pH 8. McArthur River material has stayed in the 6.5 to 7.4 range, and the Rosebery tailings predominantly above pH 7. Similarly, in the acid leaching columns, despite the low pH feed solutions, the MIM and LNO

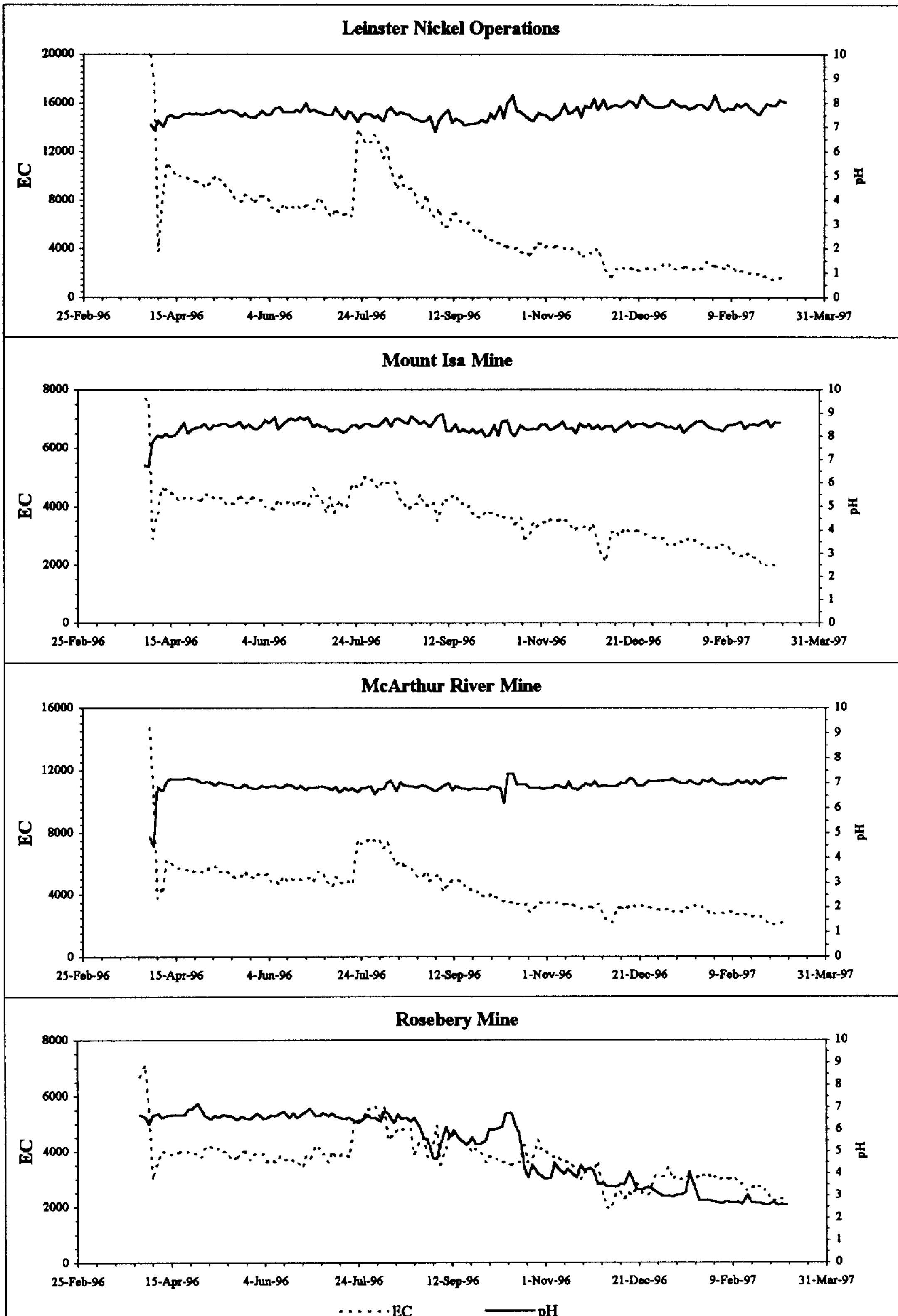

Figure 3: Acid Column Discharge pH and EC Measurements

leachates have remained alkaline, and the McArthur River discharge around neutral. Significantly, the acidic columns of both MIM and MRM tailings have persistently produced a higher pH discharge than the respective water flush columns. The only column to develop an acidic discharge has been the Rosebery leaching column, which, after 6 months, slowly began to decrease to a level around 2.5. Acid column discharge pH and EC data are given in Figure 3.

All column discharges started off with high EC values (3,700 to over 20,000 uS/cm), but the water flush discharges quickly dropped off to stabilise at minimal levels, generally <1,400 uS/cm. The EC of the acidic column discharges increased steadily during the recycling feed mode, but then started to drop subsequent to introducing the once-through system. Leinster tailings gave the highest EC readings until the Rosebery acid column discharge pH dropped below 4, resulting in a relative rise in EC values. Despite aeration of all feed solutions, and the slow drip flowrate, the redox potential was low for all discharges, in the range 80 to 170mV. While these Eh readings gradually dropped over time, they have remained constant relative to each other.

Leaching. Typically in the water columns, after a first flush of high metal concentrations, the solute values dropped off rapidly, McArthur River being a notable exception, where Zn levels remained relatively constant, and Pb, while erratic, have not decreased over time. Copper was low in all column discharges, which is consistent with the very slow reaction-rate of predominantly chalcopyrite ore.

Despite the buffering affects of acid consuming minerals, there has still been some significant leaching from the acidic columns, as demonstrated by the high EC values. However, the highly alkaline conditions of the Mount Isa material have resulted in consistently low discharge assays (Pb <4 ppm, Zn <14 ppm, Cu <2 ppm.). In the McArthur River and Rosebery acid columns Zn values have been erratic, but relatively elevated (MRM 1400ppm; PRM 700 ppm). Nickel values in the Leinster column gradually but continuously increased over time after an initial high flush and subsequent drop. Graphs of the acid column discharge assays are given in Figure 4.

Continuous metal extraction from the water columns has been calculated from the weekly sample assays and discharge volumes, and are very low. Recovery calculations for the acid leaching columns are complicated by the initial recycling feed method, but it is estimated that approximately 40% Zn recovery has been achieved to-date from the MRM and PRM acid columns, with Pb recovery much lower at >10%. Copper recoveries are negligible from all the columns. Nickel extraction from the LNO acid column is estimated at less than 20%, but increasing. Mass balance calculations at the end of the tests, with comparisons of initial and final assays of the column material, will be used to confirm these progressive extraction calculations.

Pre-leach treatment. Work into the most appropriate pre-treatment methods for each of the case studies is also underway. As there is little correlation between particle size and metal contents in any of these case-study tailings, a size separation is not suitable. Total sulphide flotation tests have been carried out on all of the case-study materials. The Rosebery tailings have responded well to flotation, though requires further work to improve precious metal recoveries. Initial test results are given in Table 5. Both Mount Isa and McArthur River materials are also amenable to flotation, but further tests are currently underway to upgrade the concentrate. The Leinster tailings material does not appear responsive to flotation, largely due to the build-up of alteration products around the sulphide mineral grains, but the use of gravity, heavy medium and magnetic separation methods are all being investigated.

Table 5. Rosebery Total Sulphide Float Results

Metals	Concentrate Assays	Conc. % Recovery	Tails. % Recovery
Pb	1.5 %	74.5	25.5
Zn	6.8 %	84.66	15.34
Cu	0.27 %	84.03	15.97
Fe	36.8 %	79.05	20.95
Ag	74 g/t	59.99	40.01
Au	4.4 g/t	26.76	73.24

Backfill Testwork and Brick /Block Manufacture

Mine backfill, agglomeration methods and block construction all require some form of stabiliser or binder to give the final product sufficient strength and cohesion for their respective applications. These are usually either small percentages of cement, or inexpensive, readily available additives such as lime, furnace slag, flyash and gypsum.

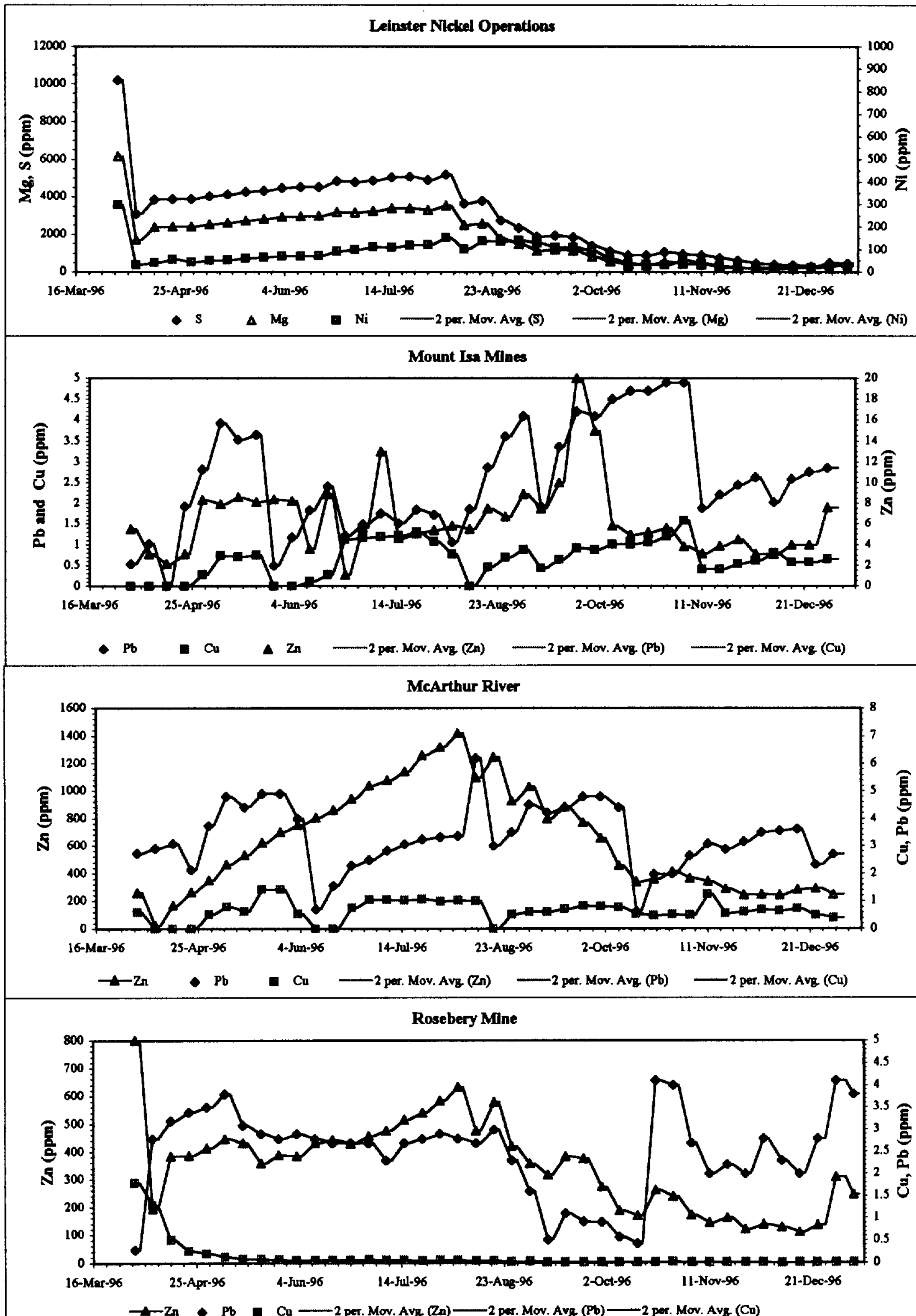

Figure 4: Acid Column Discharge Metal Assays

Backfill. Mount Isa Mines tailings have been used to test various additives and a range of mixes as these were the most readily available of the case-study materials. Initially, unconfined triaxial tests were undertaken on 8in (200mm) long, cast cylinders, at 7, 28, 56 and 90 days curing time, using MTS and Tinius Olsen compressive strength testing machines. All subsequent trials have used small 3"/80mm cast cylinders, testing with 100KPa confining pressure on a standard Wykeham Farrance 10KN stepless compression test triaxial machine, also at 7, 28, 56 and 90 days. All tests so far have used whole-tailings samples, inclusive of the fines. Various combinations and ratios of cement, slag and lime have been tested, together with direct comparisons of different cement and slag types. Once the most promising mixes had been identified, similar cylinders were cast using the other case-study tailings for assessment of their backfill potential. Table 6 summarises the combinations tested so far and initial results.

Table 6. Backfill Trial Test Results (MPa)

Trial Mix	Ave.7Day	Ave.Test
6% Cement	1.01	1.30
3% Cement	0.48	0.68
3%Cem+3%Slag	0.76	1.15
2%Cem+4%Slag	0.63	0.96
2%Cem+2%Slag	0.53	0.67
1.5%Cem+1.5%Slag	0.42	0.52
3%=15.Lime+85.Slag	0.54	0.57
Portland Cement(2+4)	0.63	0.96
Ciment Fondu(2+4)	0.55	0.61
RMIT Slag(3+3)	0.55	0.92
Isa Smelter Slag(3+3)	0.89	0.93
MIM Tailings (2+4)	0.63	0.96
MRM Tailings (2+4)	1.05	1.07
LNO Tailings (2+4)	0.87	0.89
PRM Tailings (2+4)	0.29	0.27

While some of these trials are still in progress, initial results are good, with strengths close to the backfill requirement of 1MPa being achieved with some mixes. The fines contained within the tailings have a significant binding effect themselves, resulting in a substantial reduction in the amount of cement additives necessary and making McArthur River tailings considerably more effective than the Leinster tailings. The coarser Rosebery material used for this study has notably lower strength test results.

Portland cement appears to be the most amenable type for conventional, underground backfilling. However, there may be applications where the quick curing, high strength Ciment Fondu (a hydraulic binder based on calcium aluminates, from Lafarge Fondu International) has better properties. For example, backfilling of final open-cut voids with a Ciment Fondu additive could enable later underground extraction of remnant ore beneath or alongside the pit excavation. There may also be future applications for underground 'Fondu' backfill in situations where low viscosity/high water content is necessary. Comparison of slag types from various sources has shown that locally available slag from the Mount Isa smelter is superior.

Blocks and Bricks. Mount Isa tailings have also been used for most of the block trials. The tailings have been mixed with various proportions of cement, flyash and lime as binders, and coarse mine waste products including slag and heavy media rejects as aggregate. The mixes are cast in rectangular block presses and vibrated for two minutes. The resulting blocks are cured for 7 days and then tested using an MTS compressive strength testing machine. Results so far have shown that the best of these tailings blocks, using less than the normal 15% cement, are at least as strong as traditional cement blocks (8MPa). The addition of flyash can also significantly reduce the amount of cement required. Work is also underway to develop a high-speed production system that will allow manufacture of such blocks within a continuous recycling stream and at a rate consistent with the needs of mine construction.

Tailings brick manufacture, investigated in association with commercial brick makers, includes dried 'mudbricks' and kilned refractory bricks. Both of these methods use only the smallest size fractions, but trials are underway on the whole tailings material. These tailings are generally deficient in clay minerals, but it is the physical and chemical properties of clays that are vital to the cohesive strength of the final brick product. Consequently, these trials are also investigating the addition of various proportions of clay to the tailings material. Although this work has just started, the resulting bricks are likely to be suitable only for low strength applications.

Chemical Stability Tests. All products from these backfill and construction material studies are subjected to acid-bath tests to assess their resistance to leaching and liberation of contaminants. For every test batch mixed, an additional cylinder, or block, is made specifically for leach tests. These are placed in sulphuric acid solution (pH 3) for a minimum of one week, and are then removed, dried and sliced for microscopic examination. The solution residue is sent for ICP-AES analysis. So far these tests have shown some surface carbonate reaction to the acid, but no 'leaching' or elevated metal assays in the solutions.

Soil Development Studies

Each of the case study materials were analysed for C, N and P to establish the base level of macro-nutrients. In all cases, these were found to be low and deficient for plant needs. Analyses of various traditional additives have shown that sewage sludge is particularly good for improving the nitrogen, phosphorous and organic contents, and also increases porosity, cationic exchange capacity and decreases the bulk density of the tailings. However, chemical contents vary widely depending on the source, and care has to be taken not to introduce additional contaminants. Flyash, while not contributing to the fertility of the tailings, greatly increases cohesion and improves the physical characteristics by altering the grain-size distribution. The natural binding properties of both these additives are being tested in mixing trials and have produced good agglomerates. The pellets produced are generally oval in shape and range between 0.2-0.4in (5-10mm) in length. Pellet stability is being tested to assess material handling limitations.

The introduction of coarse organic material, using either compost or municipal 'green' waste, also adds to both fertility and structure. Initial studies have suggested that an input of 30 percent total additives, in a 2:3:3 ratio of compost:sewage sludge:flyash, provides the best combination of plant nutrients and physical structure.

A review of solid particle mixing methods determined that a simple inclined rotating drum type, with some internal baffles is the most appropriate means for both mixing the tailings and additives, and for agglomeration. Designs for control of the final moisture content of the material are also being developed to maintain the agglomerated structure and avoid material handling problems. The most promising of the resulting mixes are to be used in potting trials to test the soil fertility and ability to support continuous plant growth

Summary

Most of the laboratory based work for this project is nearing completion, but there are still some important tests and procedures to be carried out. Small, bench-scale leaching tests are in progress to determine whether the metal leaching potential can be improved, and to simulate a slurry leach process that can be incorporated into the recycling system. These tests use multiple small columns in series, with sparged air and an acidified ferric leach solution. Alternative lixiviants suitable for individual case-study tailings are being investigated through a review of existing technology and current research programmes.

A bulk sample from each case-study is to be processed through each of the stages to assess the technical recycling feasibility of each tailings material. This will aid the final design requirements of individual recycling flowsheets. The flowsheets are to be the basis of economic modelling to evaluate the recycling potential of each case-study, within the context of the whole mining operation.

The general economic viability of the recycling system is being assessed in comparison with conventional methods of tailings management and rehabilitation. Results to date indicate that the recycling system is likely to have only limited application as a means of rehabilitation in historic mining sites. The system is more appropriate for tailings at mine sites that are still in current operation, where recycling can be integrated with mine planning and management strategies. There are three scenarios where the system appears to be most applicable. These are: a) where there is pre-existing reason to excavate the tailings (for example, for underground backfill requirements), b) where there is a significant metal resource in the tailings, and c) where the tailings in their present condition pose a significant environmental concern. The greatest potential for this proposed tailings recycling system is undoubtedly as an alternative method of treating mine tailings in future mining projects. Ideally such a system should be incorporated into pre-mine feasibility studies and long-term planning in a pro-active approach of eliminating the need for tailings dams altogether.

Review of current technologies and initial indications from this research suggest that the recycling of base metal mine tailings may be technically and economically feasible, as well as environmentally desirable. Recycling tailings would effectively remove the problem of long term storage of potentially toxic mine waste, and could further aid mine environmental programmes by improving the visual impact through revegetation. As the mining industry strives to achieve "best practice environmental management", the potential to recycle mine tailings offers a significant opportunity to reduce the impacts of mining and improve the options available for future land use.

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