FUTURE TRENDS IN PAL PLANT DESIGN FOR NI/CO LATERITES

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1. INTRODUCTION

Forty years after the construction of the first pressure acid leaching plant for nickel laterites by Freeport at Moa Bay, Cuba, three new PAL plants are now in operation in Western Australia. Although modern designs of autoclaves and heat recovery systems have been adopted, the basic pressure leaching concept at the heart of the Bulong, Cawse and Murrin Murrin plants is, in fact, largely unchanged from Moa Bay. The main differences lie in how the nickel and cobalt are recovered and refined, for which each operation varies from each other as well as from Moa Bay. Murrin Murrin is the closest to Moa Bay with mixed sulphide precipitation, a strategy which was prudent in view of the large throughput and capital investment. Bulong, with the longest development time, adopted a direct solvent extraction approach to reduce capital cost, in which cobalt and nickel are extracted sequentially from the pressure leach solution. Cawse, on the other hand, selected mixed hydroxide precipitation followed by ammonia releach, which allowed use of the nickel solvent extraction step commercially proven at Queensland Nickel. This strategy enabled Cawse to catch up with the other two, despite being a later starter. Abbreviated flowsheets are illustrated in Figures 1-3.

The current field of hopefuls for the next wave of PAL plants are following the fortunes of the first three with more than a passing interest, and will be hoping to benefit from the successes and pitfalls emerging from the experience of their predecessors. Although they will be under pressure to minimise risk, they will also be looking at process improvements to gain cost and operational advantages, as will be the present plants for possible future expansions. Some of the available process options for new projects or plant expansions are discussed in this paper.

2. POSSIBLE PROCESS OPTIONS FOR THE NEXT WAVE

These include process steps applied in other operations, emerging technology and innovations previously considered for PAL plants but not yet commercially applied.

2.1 HIGHER LEACH TEMPERATURE AND PRESSURE

All current PAL plants, including Moa Bay, operate at around 250^{0}C in the autoclaves. Amax operated at 260-270^{0}C in the nineteen seventies in their pilot plant campaigns for the Prony project in New Caledonia[1]. They reported that benefits of higher temperature included faster leach kinetics, reduced retention time and therefore smaller autoclaves, lower acid consumption and improved purity of the resulting leach solution. On the debit side, the operating pressure rises significantly, requiring increased autoclave wall thickness. Also, unless indirect heat exchangers are used (as in the Amax flowsheet), the present limitation on the maximum operating temperature of the currently used positive displacement pumps means that the higher operating temperature will have to be achieved using direct steam injection. The main incentive for future plants will be the ability to achieve a greater ore throughput per leach train, which should result in capital cost and footprint area savings. It is reported[2] that Inco's new Goro pilot plant is designed to operate at 270^{0}C.

2.2 INDIRECT HEAT EXCHANGERS FOR PAL PREHEATERS

All three new PAL plants use splash type preheaters, in which recycled steam from the flash tanks is contacted directly with the feed slurry in order to recuperate heat and preheat the autoclave feed. While being the technically safest option, this requires interstage pumping, dilutes the autoclave feed slurry and resulting leach solution, and requires the leach feed pumps to operate at high temperature. The use of indirect heat exchangers instead of splash vessels is shown in Figure 4[3].

Fig. 1

Simplified Bulong Flowsheet

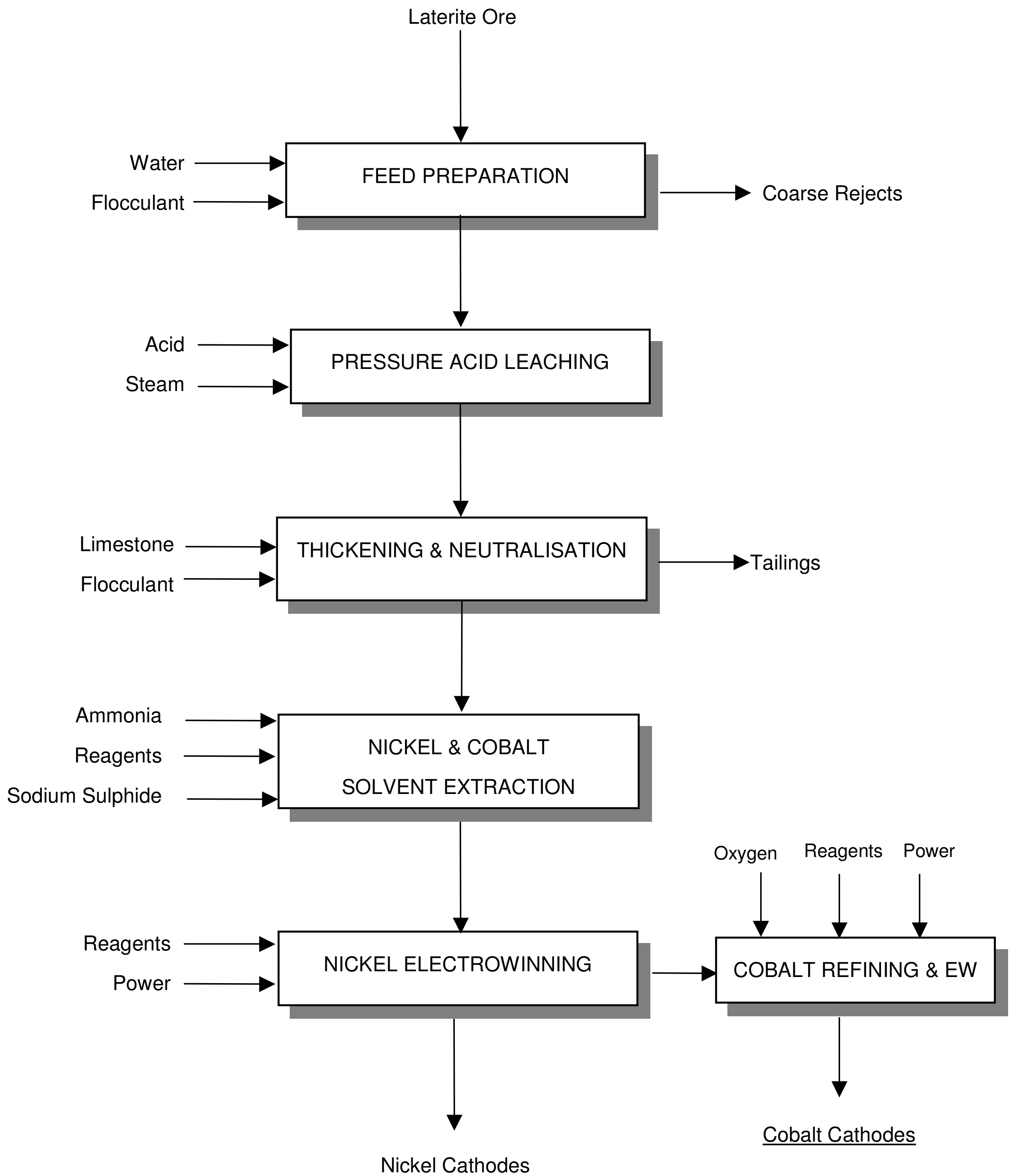


Fig. 2

Simplified Murrin Murrin Flowsheet

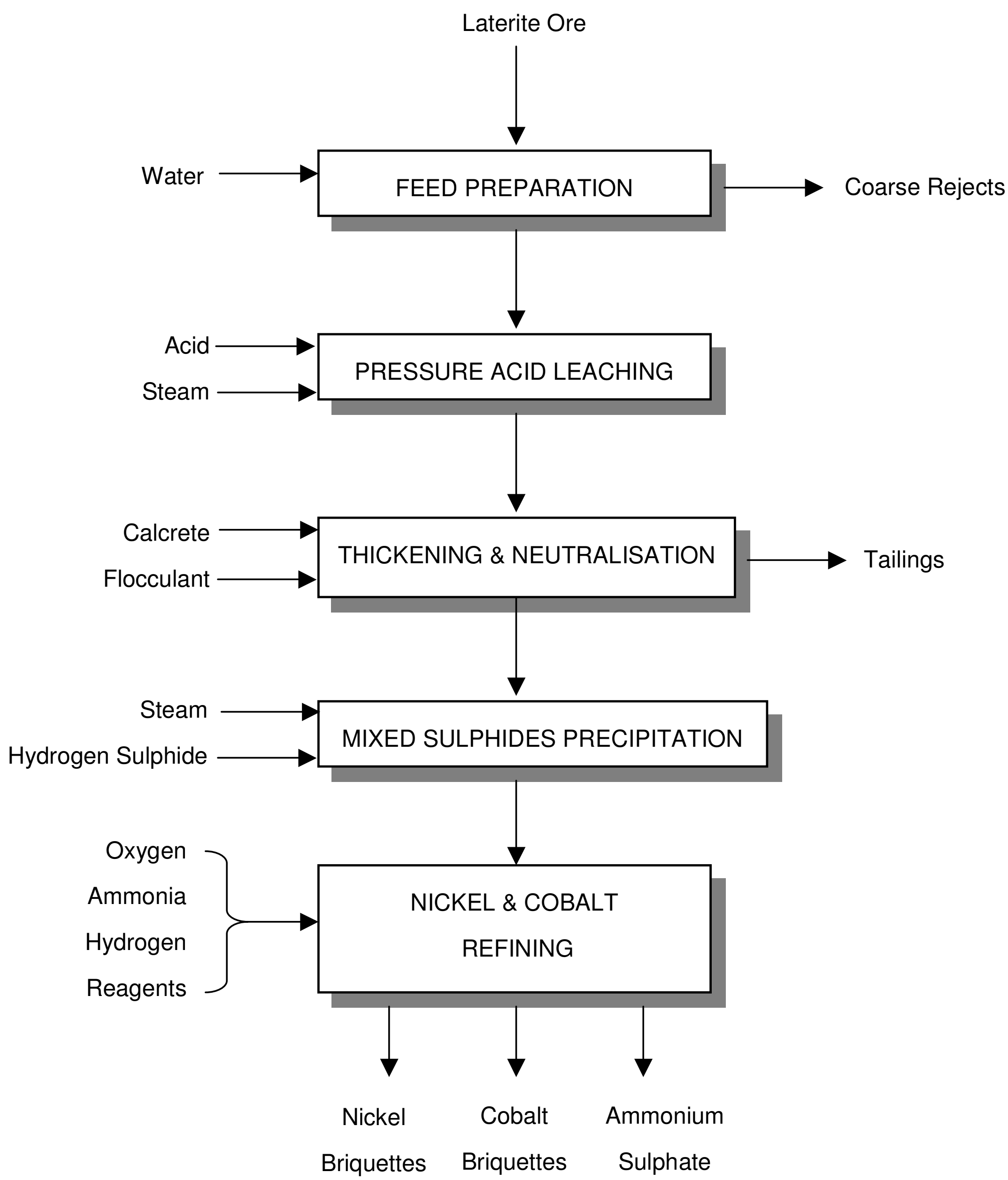
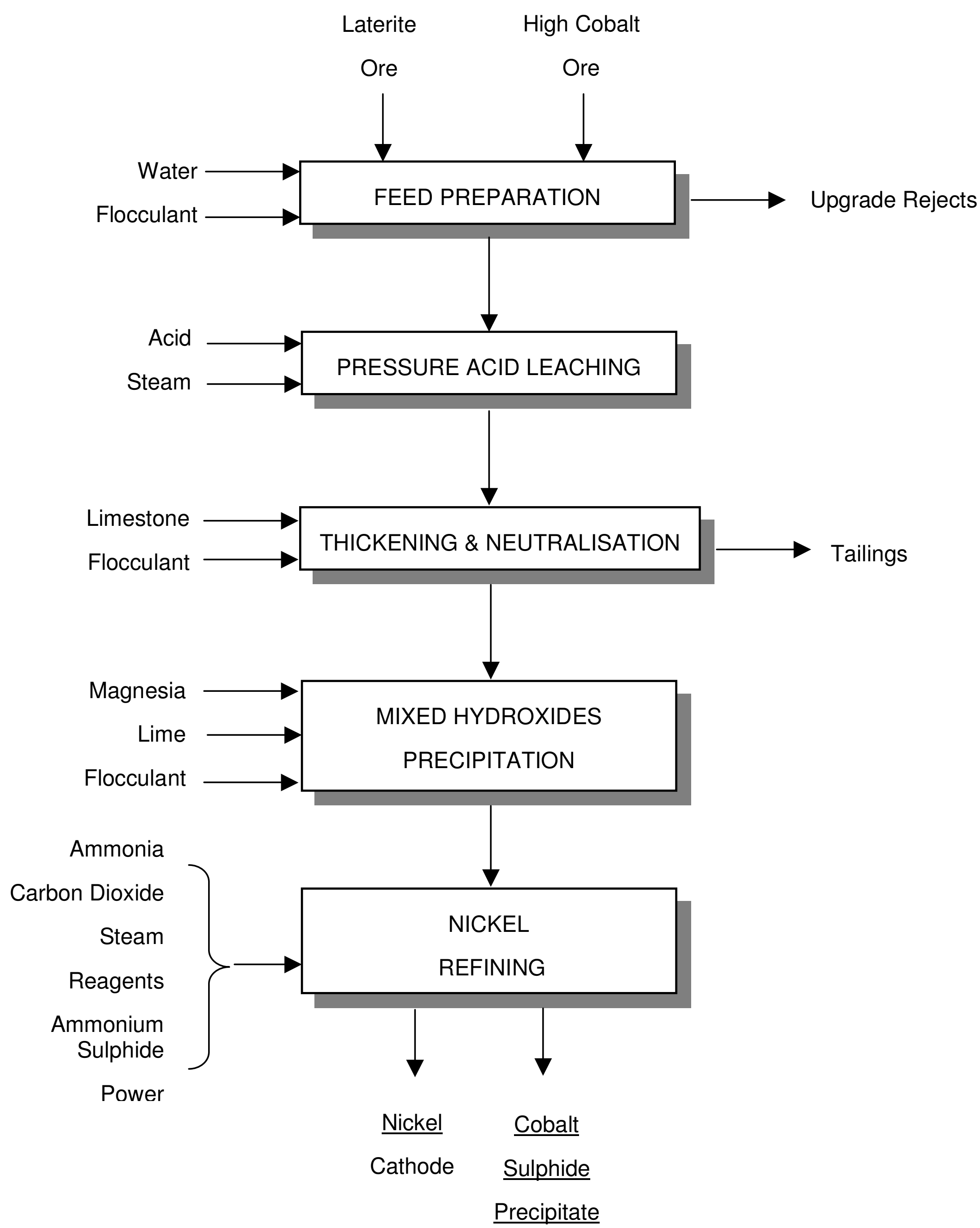


Fig. 3

Simplified Cawse Flowsheet



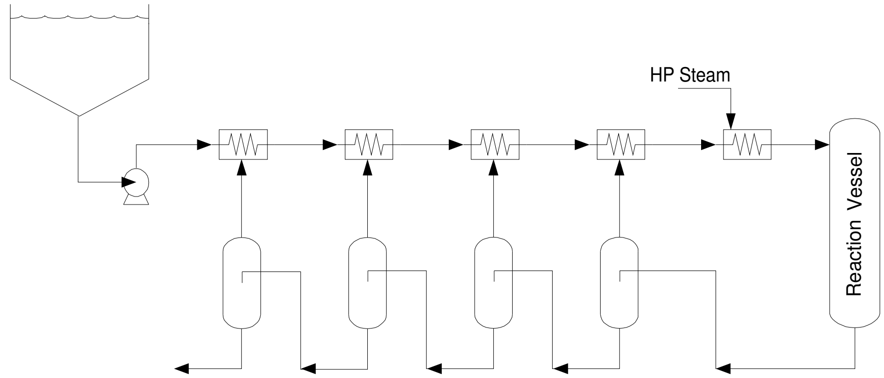


Fig. 4 Indirect Heat Exchanger Arrangement

In this arrangement, there is a single pumping station operating at the cold end of the preheating train. Final preheating is achieved by indirect steam heating, and pulp dilution with recycled steam is avoided. It would obviously be particularly advantageous to adopt this system when designing for higher leaching temperature. Indirect heat exchange was used by Amax in their pilot plant, and is in routine operation in alumina plants. One of the major challenges faced by the new WA PAL plants was the absence of proven heat exchange data for the viscous feed slurries with significant content of clays, which have much different characteristics from the laterite slurries tested by Amax. Large scale pilot plant work would have been required to develop adequate data, and even then there would have been a risk of scaling of the heat exchange surfaces. During the development phase of the Bulong project, the use of indirect heat exchangers was seriously considered as either a total or partial replacement for splash tanks. In the partial arrangement, heat exchangers were to be used for the final one or two preheating stages, which would have reduced the operating temperature of the high pressure pump and eliminated the need for direct steam injection into the autoclave. Splash tanks were to be used at the cold end of the preheating train where the slurry viscosity effect was greatest. In the final event, the use of indirect heat exchangers was deferred until it could be tested in the commercial plant for application in the planned subsequent expansion.

2.3 CENTRIFUGAL AUTOCLAVE FEED PUMPS

It is current practice to employ positive displacement diaphragm pumps for the high pressure autoclave feed duty. The maximum allowable operating temperature limit for existing pump designs was a major plant design issue, as it affected the achievable preheat temperature and energy efficiency of the pressure leaching system. The temperature limit for Geho pumps has been reported to be 200^0C[4]. Where multi-stage flash/preheating is adopted, this limit can prevent utilisation the full utilisation of the available energy from the flash let-down system. One approach is to accept a lower energy efficiency and incorporate fewer stages, which will lower the required operating temperature of the autoclave feed pumps[5]. Alternatively, centrifugal slurry pumps could be used, which have been operated successfully at temperatures in excess of 200^0C in the alumina industry. The advent of the WA commercial PAL plants makes it feasible to evaluate centrifugal pumps under realistic conditions.elimination of feed thickening

2.4 ELIMINATION OF FEED THICKENING

Even with the assistance of saline water, the settling characteristics of the clayey WA ores are poor compared with tropical laterites such as at Moa Bay. The resulting low thickened density means larger autoclave volume, higher water requirement and more dilute leach solution. One available countermeasure is to adopt a feed preparation design which does not include a thickening step. This was done at Murrin Murrin where slurrying is carried out by SAG milling, and a buffer of agitated pulp storage tanks is included ahead of pressure leaching. Such an arrangement was adopted for uranium ore treatment plant design in the seventies. It is understood that Murrin Murrin was also designed to use water at 70^0C, which will reduce the viscosity of the slurry for screening, pumping and agitation[5]. The inclusion of an ore upgrading circuit may affect the feasibility of eliminating feed thickening.

2.5 NEUTRALISATION WITH HIGH ACID CONSUMING ORE

In this arrangement, high acid consuming ore is used in place of all or part of the limestone to neutralise residual leach acid at atmospheric pressure. The partially leached ore then joins the feed to the autoclaves. This improves the economics of treating the high acid consuming ore and, in some cases, may significantly add to the economic ore reserves. The requirement for limestone will be eliminated or significantly reduced with resulting cost savings. This concept was an integral part of the Omnivorous Process which Amax extensively evaluated in the seventies[7]. They found that some ores had to be calcined to obtain adequate neutralising activity. A typical flowsheet is depicted in Figure 5. In an alternative concept, the use low grade ore for neutralisation could be considered.

2.6 REPLACEMENT OF MAGNESIA WITH LIME FOR NI/CO PRECIPITATION

Magnesia consumption is a significant operating cost item in the hydroxides precipitation route. A potential lower cost alternative is to use lime in place of magnesia, combined with releaching in an ammonia/ammonium sulphate medium instead of ammonia/ammonium carbonate. This flowsheet is being proposed for the Ramu Project in PNG[8]. Steemson[9] concluded that the process has the additional advantages of eliminating sulphate carryover problems and reducing the transfer of manganese. One disadvantage is reduced releach efficiencies, requiring further leaching of the residue with, for example, sulphuric acid and sulphur dioxide to recover and recycle nickel and cobalt. Others include a higher mass of releach residue due to the presence of gypsum, the need for a lime boil circuit in lieu of steam stripping to recuperate ammonia from releach residue and bleed streams, and slower stripping kinetics in the subsequent nickel solvent extraction circuit leading to the requirement for an additional stage. The cost benefits of the lime precipitation route will depend on the relative cost and availability of the reagents.

2.7 PULSED COLUMNS INSTEAD OF MIXER-SETTLERS FOR NI/CO SOLVENT EXTRACTION

All three of the new PAL plants contain solvent extraction (SX) circuits using mixer-settlers to perform various duties, and these facilities represent significant cost items. Mixer-settlers were favoured as the technically safe option, well proven on comparable applications at other operations. Pulsed columns contactors offer significant potential advantages for nickel/cobalt SX circuits, which frequently contain multiple stages. These include lower capital cost, reduced footprint area, greater tolerance to solids, ease of crud removal, low organic entrainments and totally enclosed construction. However, although well known in other industries, column contactors have been little used for metallurgical applications[10]. Reasons for this include the dominance of copper SX plants with a low number of stages, and the lack of commercially available designs and reliable testing and scale-up methods. In recent years, pulsed columns have been more widely promoted for metals extraction[10], and a large facility has been supplied by Bateman for uranium extraction at the Olympic Dam operation in South Australia, which is shown in Figure 6. Pilot plant programs for Ni/Co SX have been recently reported[12,13].

2.8 ELIMINATION OF STARTING SHEETS FOR NICKEL EW

Current nickel electrowinning (EW) practise is to produce intermediate starting sheets on titanium or stainless steel mother blanks, then transfer the sheets to other cells for final cathode production, which is a labour intensive operation. In the copper industry, the use of starting sheets was eliminated by the development of direct deposition of cathodes on to stainless steel blanks by Copper Refineries for both copper refining and electrowinning. This was accomplished as a result of an extensive development program, which included automatic and semi-automatic stripping machines. It seems a reasonable expectation that similar results can be achieved for nickel EW, which should result in significant cost savings. Cobalt EW on to stainless steel blanks is already practised.

2.9 APPLICATION OF EMEW CELL

The EMEW cell is a tubular, totally enclosed design, with high solution flow rates over the electrode surfaces. This provides a more rapid supply of metal ions for deposition at the cathode compared with a conventional EW cell as illustrated in Figure 7[14]. Advantages of EMEW cells include ability to

Fig. 5

Neutralisation with High Acid Consuming Ore

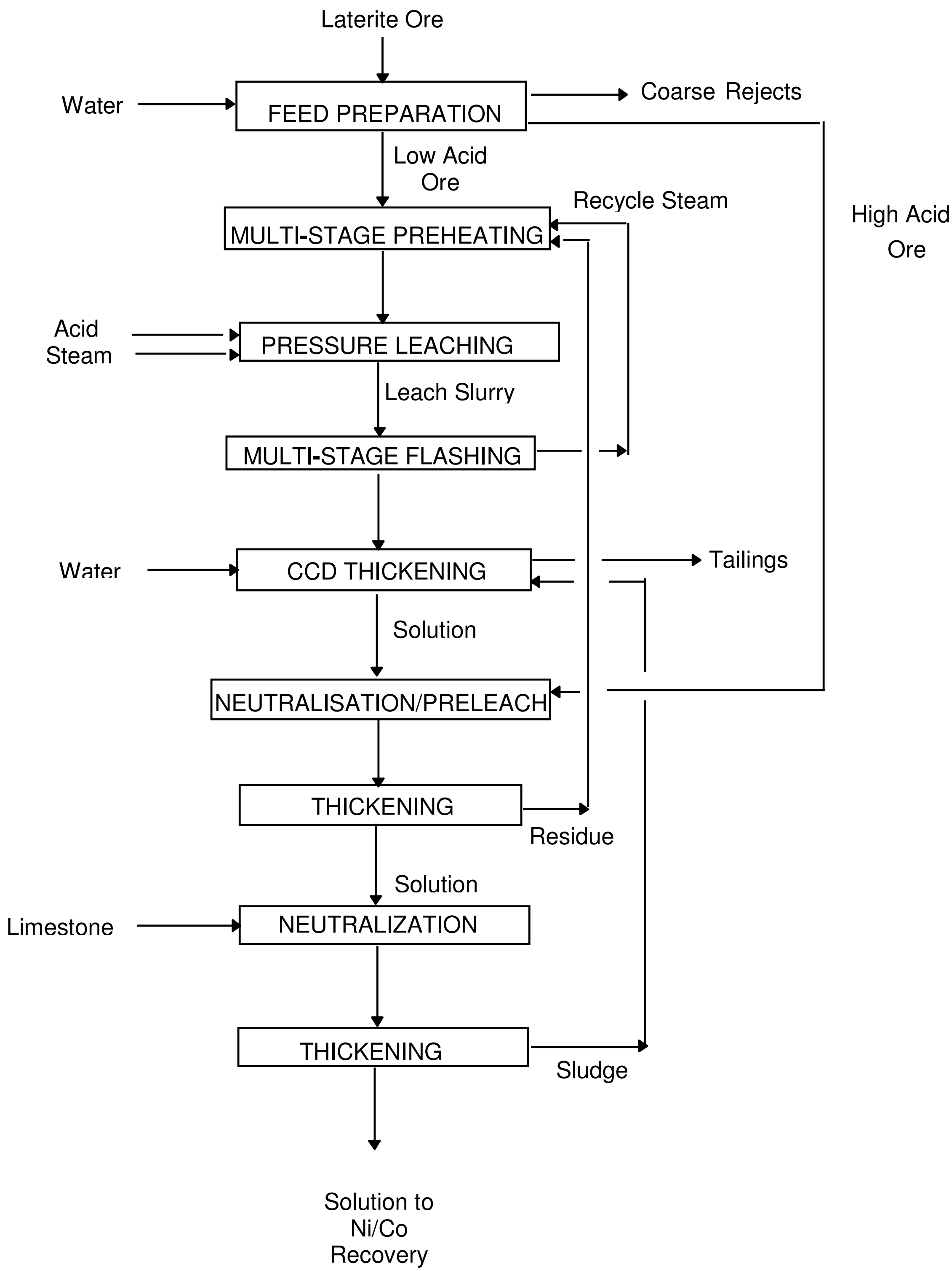


Fig. 6 Bateman Pulsed Column Installation at Olympic Dam

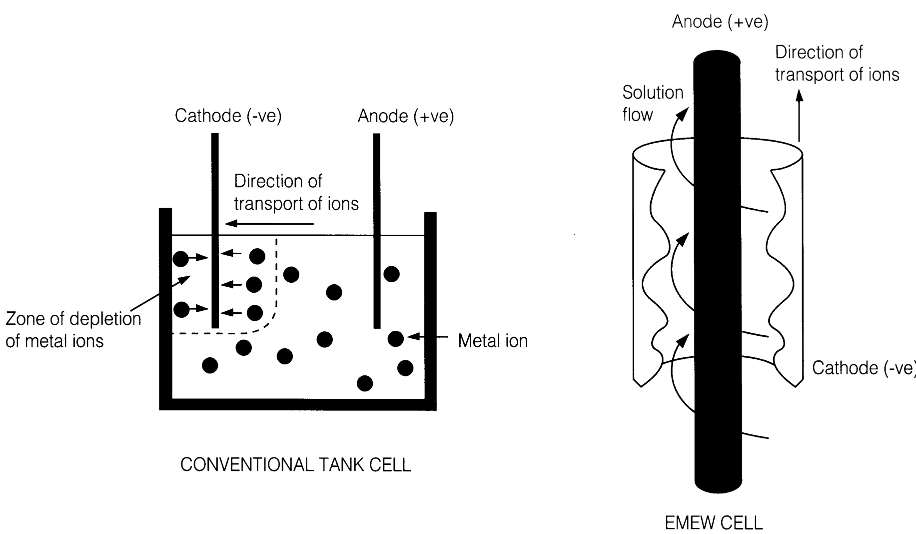


Fig. 7 Conventional vs EMEW Cell Concept

handle a wide range of solution concentrations, increased current density with normal electrolyte concentration, ability to treat very low grade solutions at acceptable current efficiency, elimination of acid mist problem, and simple modular construction. When coupled with SX, they are less sensitive to organic carry-over, which may allow operation without high efficiency organic removal equipment. The totally enclosed construction significantly alleviates the safety/health issue involved with nickel EW. The main disadvantage is the relatively small size of the cell, though larger cells are being developed. The design has been successfully operated in small commercial copper operations, and a nickel EW installation is being operated by Asarco in Texas. A number of test programs are currently being carried out for both nickel and cobalt, and previous work has shown that the cell is capable of treating low grade ammoniacal solutions. The design offers the potential for cost reduction, flowsheet simplification and safety benefits for both primary and by-product applications.

2.10 APPLICATION OF MEMBRANES AND LIGANDS

Membrane technology is well established for wastewater treatment and environmental remediation applications, which can offer the possibility of reagent recovery and reuse. However, there is a growing trend to develop applications for process enhancements such as solution concentration, purification, selective ionic separation and acid recovery[15]. For example, commercial applications in copper hydrometallurgy include leach solution concentration, water balance control and electrolyte purification[16]. The technology could also offer opportunities for cost savings, process improvement and simplification in PAL flowsheets.

Another area of development is molecular recognition technology (MRT), which involves the use of chemical ligands to selectively complex with ions in solution. Ligands are already in use for the purification of copper electrolytes[17]. Opportunities for Ni/Co PAL applications include electrolyte purification and treatment of low grade solutions.

3. FUTURE DEVELOPMENTS

In the longer term, other new technical developments will be considered in the quest to achieve process improvements and reductions in capital and operating costs. Some possible contenders include:

3.1 ORE UPGRADING BY FLOTATION

Some laterites have already been shown to be amenable to simple upgrading by removal of low grade coarser material by screening or cycloning. Another possible approach is flotation, which has given some encouragement in the past, though not enough to lead to commercial application[18]. As the characteristics of laterites vary widely, flotation may be worth pursuing for some deposits. The commonly fine nature of most laterites means that grinding may not be needed, thus rendering flotation relatively inexpensive. Therefore, it may be an economic proposition even if there are significant metal losses with the tailings.

3.2 PRESSURE LEACHING/OXIDATION OF BLENDED LATERITE/SULPHIDE FEED

Given the commercial application of PAL technology for laterites and pressure oxidation for gold, zinc, uranium and copper ores, it should be feasible to treat a blend of laterite ore and sulphide ore or concentrates. Potential advantages include the on-site production of metal from the sulphide, utilisation of the acid and heat generated from the sulphide in the autoclaves for leaching the laterite, and economy of scale for the combined operation. Such a concept could be particularly advantageous when low grade or impure sulphide is involved. A possible variation would be to use pyrite to replace or supplement nickel sulphide as the source of sulphur. Republic Steel developed a pressure oxidation process applicable to both laterites and sulphides up to pilot plant level in the seventies[19]. However, sulphur and pyrite were added to sulphidise the laterite for pressure oxidation.

3.3 EXTRACTION AND RE-USE OF RESIDUAL PAL ACID

The PAL process requires a relatively high residual acid content, typically in the range of 30-40 g/L. This is costly in terms of both additional acid cost and limestone for neutralisation. Thus, extraction and re-use offers the opportunity for a significant saving in operating cost. The possible application of membranes is referenced above in Section 2.10, although gypsum scale control may be an issue. Solvent extraction and ion exchange are also candidates. IX has been commercially applied for acid recovery from the copper refinery bleed stream at the Kidd Creek copper refinery in Canada[20]. A considerable amount of testwork has been done using various SX extractants, and a commercial plant was designed for a copper leaching application in Russia, though the project was not constructed.

3.4 ALTERNATIVE DIRECT SX PROCESES

Bulong is the only operating PAL plant employing direct SX. However, it is understood that Inco are testing an alternative direct SX process for their Goro project in New Caledonia[2]. In principle, the direct approach offers relative simplicity and reduced capital cost, especially if more selective extractants are developed. Thus, further development can be expected. Another opportunity for a more selective extractant is for the recovery of cobalt from the cobalt SX strip solution in the current Bulong flowsheet to reduce capital and operating costs.

3.5 APPLICATION OF RESIN-IN-PULP

All four operating PAL plants include multi-stage CCD circuits to wash the nickel and cobalt values out of the leach pulp using a series of large diameter corrosion resistant thickeners. These circuits involve significant capital and operating costs, occupy large footprint area, and require a significant quantity of wash water which dilutes the feed to the associated Ni/Co recovery facilities. A possible option is to use a resin-in-pulp (RIP) system, which employs a resin to recover the nickel and cobalt values from the leach pulp without thickening. Such systems have been commonly used for commercial uranium recovery, especially with lower grade and difficult to settle ores. The widely used, and highly successful, CIP process for gold is a similar concept, in which carbon plays the role of the resin. It is interesting to note the current interest in the use of resins for gold recovery. For the potential PAL plant application, the best approach may be to extract the nickel and cobalt together in a single CIL circuit, then separate and purify them for individual recovery from the resulting concentrated eluate solution, possibly using SX as in the uranium ELUEX plants. Final recovery could be by EW, hydrogen reduction etc. The eluate solution could be either sulphate or chloride based. The challenge for PAL plants is to find an existing resin or develop a new one capable of extracting the nickel and cobalt with a reasonable degree of selectivity, so that the resin loading is not dominated by another element. It may be preferable to drop out elements such as iron ahead of RIP to alleviate the task of the resin. A notional flowsheet is shown in Figure 8.

3.6 BY-PRODUCT SCANDIUM RECOVERY

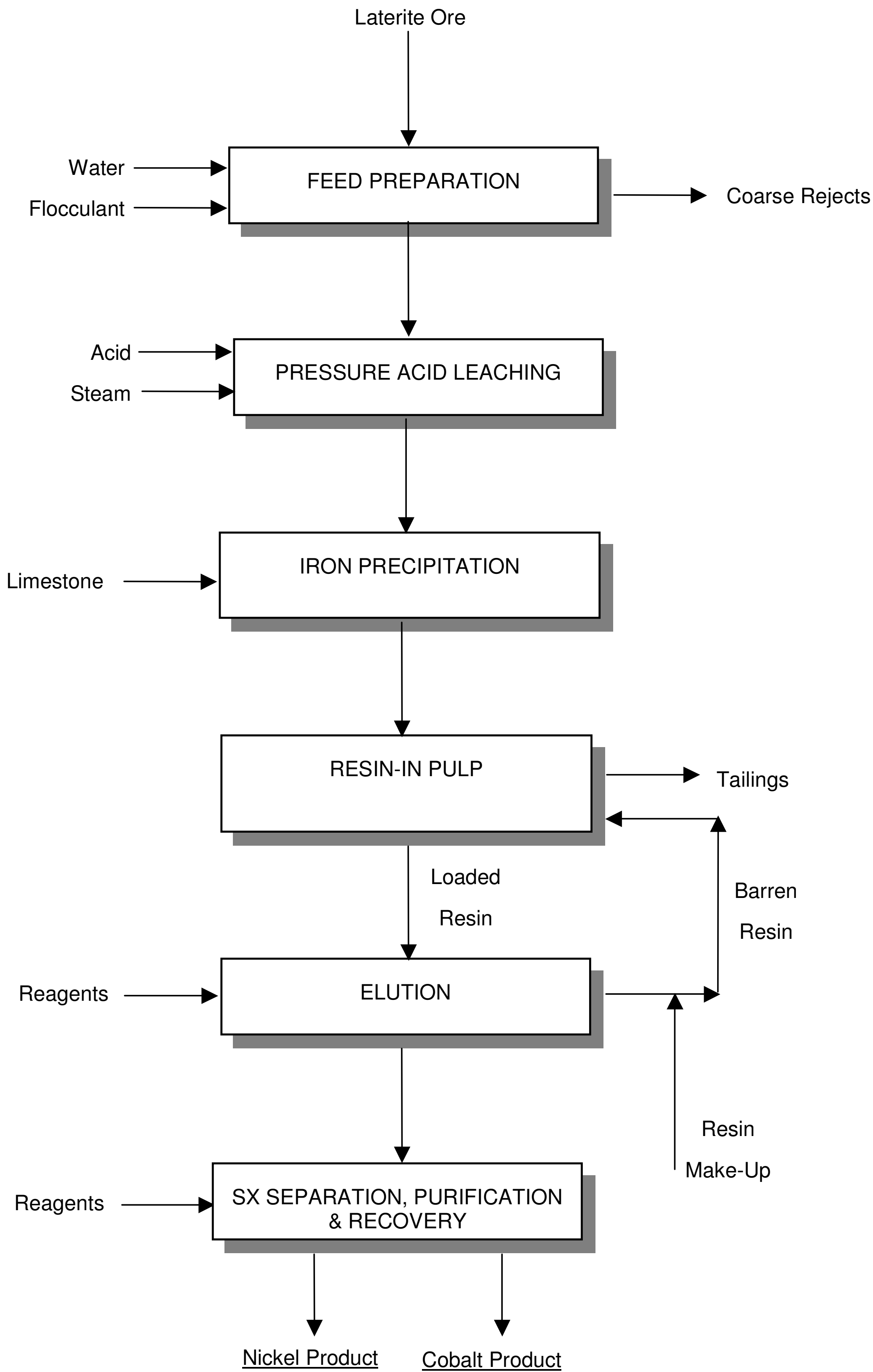
Scandium is a potentially recoverable valuable by-product for a number of laterite deposits when treated by the PAL process. Preliminary testwork has shown that SX or IX techniques may be applicable[21]. As more PAL projects are developed, and the basic technology settles down, there is likely to be increasing interest in possible by-products such as scandium in order to improve economics, especially for lower grade deposits.

3.7 METAL PRODUCTION BY HYDROGEN REDUCTION OF SX ORGANIC

The recovery of metals such as nickel, cobalt, copper and iron using SX followed by direct hydrogen reduction of the loaded organic to form pure metal powders was proposed in the late sixties and early seventies. Promising testwork was reported by Burkin using Versatic Acid and DEHPA extractants[22]. Power-Gas Limited in the UK demonstrated that the particle size of the metal powders could be controlled, and tested a continuous autoclave[23]. The process operates at modest pressure, and in the temperature range of 130-200^{0}C. Under these conditions, the organic extractants are stable and can be recycled to the extraction step. Studies indicated that the process had greatest potential for nickel and cobalt, for which hydrogen reduction from aqueous solutions was already commercially applied by Sherritt. However, interest waned with declining interest in new nickel projects. In the present climate of fresh interest in laterites, the technology could be well worth revisiting as a potentially simpler and lower cost alternative to electrowinning and aqueous hydrogen reduction currently used in the new PAL plants. As the SX performance of both Versatic Acid and DEHPA varies with pH, the technology could be applied in a number of ways. For example, in the Bulong flowsheet Versatic is already used to extract nickel, and hydrogen reduction of the loaded Versatic could replace stripping and electrowinning. Researchers also found that the hydrogen reduction process can act selectively, thus achieving metal separations, which adds further possibilities for flowsheet development.

Fig. 8.

Notional RIP Flowsheet



4. CONCUSIONS

The main thrust of the next round of PAL plants will undoubtedly be to learn from the experience of Bulong, Cawse and Murrin Murrin, and achieve commissioning and ramp-up to full production in much improved time frames. However, there will also be considerable incentive to incorporate improvements with potential for significant cost reductions, especially when they involve relatively low risk. The existing PAL plants offer the opportunity for testing and proving up improvements which are of interest for future plant expansions as well as new projects. Already, higher temperature leaching and a new direct SX process are being considered by Inco for the Goro project, and risk is being reduced by operating an integrated pilot plant. Also, lower cost lime precipitation is proposed for Ramu by Highlands, who have proven the process at pilot scale. Other available options include direct heat exchangers, centrifugal autoclave feed pumps, neutralisation with high acid consuming ore, elimination of feed thickening, pulsed column SX systems, EW developments such as the elimination of nickel starting sheets and the EMEW cell, and the application of membranes and ligands.

Time will tell as to what the longer term future holds for the PAL process, but it is likely that other new technology will be developed and adopted. Some possible candidates include upgrading by flotation, combined treatment of laterites and sulphides, residual acid re-use, new SX extractants, RIP technology, scandium by-product recovery and direct reduction of SX organic.

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