THE OUTLOOK FOR THE PAL PROCESS

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1. FORTY YEARS ON

Forty years after the commissioning of the first PAL plant at Moa Bay Cuba, three new operations are in the ramp-up phase in Western Australia. This paper attempts to assess progress of the three WA operations to date and the implications for other PAL projects waiting anxiously in the wings.

2. HOW ARE THE WA PAL PLANTS DOING?

The life and times of each of the WA PAL plants are briefly reported below, based on information available in the public arena.

2.1 CAWSE

Centaur's Cawse project was the late entrant in the "Great Laterite Race", but sprinted past the post to be first to produce nickel, in January 1999. It also appears to be ahead in the ramp-up stakes, meeting or exceeding major design criteria by May 2000, about 20 months after start-up. Ore throughput was 105% of design, and nickel production was over 90% of nameplate. The nickel cathode product was reported to average 99.76% Ni in June 2000, close to the LME grade of 99.8%, with only zinc being above specification. Consumptions of major reagents are below design. The operation is now said to be in the optimisation phase, with focus on areas such as steam, power and water to improve efficiencies and reduce costs. Cash operating costs for the June 2000 quarter were reported to be US$1.88/lb after cobalt credits at US$13.77/lb cobalt. The corresponding figures for July and August 2000 were US$2.09/lb and US$1.42/lb respectively.

Major milestones:

Sept 1998	Leaching commenced
Dec 1998	First cobalt sulphide
Jan 1999	First nickel
Jan-Mar 1999	Nickel close to 99.8% Ni, & cobalt sulphide 35-40% Co
Apr-June 1999	Ave nickel & cobalt leach extractions > 90%
Aug 1999	Cash positive
	Leach extractions 95%, overall recoveries 85%
Nov 1999	80% Ore throughput
Jan 2000	85% Autoclave availability
	Overall recoveries 90% cobalt & 87% nickel
Feb 2000	80% Nickel production
May 2000	Major design criteria met or exceeded
	Ore throughput 105% design
	Nickel production > 90% nameplate
	Major reagents consumptions below forecast

Problems encountered:

The basic process at Cawse has worked satisfactorily, as evidenced by the early achievement of high leach extractions, close to specification products and less than forecast consumptions of major reagents. Although significant problems have been experienced, these have been largely overcome and no fatal flaw has emerged. The problems encountered have been mainly related to materials, availability and operational issues. Because of the materials involved, time for procurement of replacement parts has sometimes been lengthy. In assessing these issues, in particular those connected with the pressure leaching area, it should be borne in mind that Cawse currently includes a single autoclave. Down-time should be less disruptive for an expanded multi-stream operation. Key issues include:

- Initial cracks in autoclave titanium lining welds. (Rectified satisfactorily.)
- Equipment failure and localised material corrosion due to upset process conditions, faulty lining application or incorrect material selection in the pressure leach area, such as pumps, valves and piping. (Progressive review and upgrading undertaken.)
- Poor performance of autoclave isolation valves. (Modified valves procured.)
- Bogging of autoclave agitators with sludge. (Resolved by operating strategies to control sludge formation, and modifications to allow sludge to pass through autoclave.)
- Scale build-up in desalination unit, which reduced water availability to the power station for steam generation. (Alleviated by chemical dosing, and improved operating and maintenance procedures. Long term solution is a standby desalination unit and increased treated water storage.)
- Unreliability of sulphur pumps. (Additional larger pump installed.)
- Scale build-up in the ammonia re-leach area, which limited throughput and metal production. (Alleviated by installation of duplicate lines and implementation of descaling procedures.)
- Higher than specification zinc level in nickel product. (Enhancements have been developed, and will be implemented progressively.)
- High manganese content of high grade cobalt ore which led to high lime consumption and high recirculating loads. (Countered by reducing the proportion of high cobalt ore to maintain manganese levels at less than 3%.)

Autoclave scale growth has not proven to be a significant issue, as indicated by the pilot plant testwork.

2.2 BULONG

Bulong was the pioneer of the three projects, with the development program commencing in 1988, and was second past the post to produce nickel in February 1999. It is also second in ramp-up, reporting that the plant operated close to design capacity during September 2000, some 21 months after the initial introduction of feed to the leach autoclave. Ore throughput was 98% of design, nickel production was 86% of design while cobalt was 77.5%. LME grade nickel, including impurity specifications, was achieved in June 1999; however the nickel grade subsequently dropped below 99.8% due to increased cobalt levels caused by the utilisation of one of the cobalt solvent extraction stages to combat the gypsum precipitation problem. A grade of 99.67% was reported for August 2000. The ramp-up has been lengthened by a number of extended shut-downs to carry out modifications and repairs. A cash cost of A$10,720 per tonne of nickel plus cobalt was reported for September 2000, equivalent to A$185 per tonne of ore.

Major milestones:

Dec 1998	Leaching commenced
Dec 1998-Jan 1999	Seven-week shut-down to replace defective components for leach agitators, plus modifications to SX piping
Feb 1999	First nickel
Mar 1999	Leach extractions 95%
	Throughput 80% of design
April 1999	Nickel 99.8% grade
	Close to design ore throughput
	Leach availability close to 80%
May 1999	First cobalt cathode
June 1999	Nickel met LME spec
	Cobalt 98.6% grade
Aug 1999	Leach run at design after installation of larger chokes
May-June 2000	Six-week shut-down to repair nozzles in heaters & flash tanks plus other modifications/maintenance work
Sept 2000	Plant operated close to design capacity
	Ore throughput 98% of design
	Nickel production 86% of design
	Cobalt production 77.5% of design
	Overall plant utilisation 78.5%
	Cash cost A$10,720/t Ni+Co & A$185/t ore

Problems encountered:

As with Cawse, the basic process has worked satisfactorily, as evidenced by the early attainment of high leach throughput and metal extractions, and close to design product grades. Significant problems have been encountered which have resulted in several major shut-downs, exacerbated by the lengthy time required to obtain parts made from materials such as various grades of titanium. The problems have now been largely overcome and no fatal process flaw has emerged. As with Cawse, Bulong has only a single autoclave. This, together with the absence of an intermediate nickel precipitation, means that total plant shut-downs have been required to undertake modifications and maintenance. The effects would be lessened with an expanded multi-stream operation.

- Initial cracks in autoclave titanium lining welds. (Rectified satisfactorily.)
- Corrosion and cracking of agitator hubs in autoclave. (Replacement of parts with upgraded materials.)
- Solvent extraction piping undersized limiting solution flows. (Rectified by extensive modifications.)
- Mechanical and control problems with boiler restricting steam supply to leach. (Resolved in conjunction with boiler supplier.)

- Leach throughput restricted by undersized choke valves in flash tanks. (Rectified by replacement with larger chokes.)
- Severe gypsum precipitation in the nickel solvent extraction equipment and piping, resulting in reduced flows and significant down-time for clean-out. (Alleviated by installation of by-pass piping to allow cleaning of mixer-settlers without plant shut-down, and conversion of one of the cobalt solvent extraction stages to act as a washing step to minimise carry-over of the Cyanex 272 extractant into the nickel circuit. The latter has resulted in increased leakage of cobalt into the nickel product. Follow-up action is needed to fully resolve the issue.)
- Corrosion in cobalt refinery autoclave caused by presence of chloride and poor oxygen distribution, plus bottlenecks in the cobalt refinery. (Rectification work undertaken, during which time cobalt sulphide was marketed instead of cathode.)
- Difficulties in ore preparation circuit due to handling of “plastic” clays. (Alleviated by introduction of ore drying pads.)
- Premature failure of slurry lines between flash tanks due to a broken choke valve. (Choke replaced.)
- Blockages of leach autoclave feed pump suctions with brick, mortar and scale from the preceding high pressure heater. Failure occurred in the manway nozzle, and inspection revealed potential problem with most nozzles on heaters and flash tanks. (Rectifications carried out during major shut-down.)
- Difficulties experienced in growing competent nickel starter sheets during July 2000. (Starter sheets purchased from Cawse and Rustenburg, South Africa, while problem resolved.)

Inspections during plant shut-downs have revealed that leach autoclave scale growth is relatively light, which should allow longer operating campaigns.

2.3 MURRIN MURRIN

Murrin Murrin is by far the largest of the three PAL projects, with four parallel autoclave trains and more extensive supporting facilities including a big on-site sulphuric acid plant. Mixed sulphide precipitate was produced in March 1999, and the first nickel was in May 1999, at a grade exceeding the LME specification. This was followed by the first cobalt briquettes in July 1999, grading over 99%. Mechanical completion was achieved in December 1999, and the cobalt design capacity was increased from 3000 to 5000 tonnes per annum. A “100 day campaign” was undertaken in July-October to convert the flash tanks to top entry and do other rectification and modification work, targeting consistent plant availability of 60% of design capacity. In September 2000, 22 months after start of leaching, figures equivalent to 46% of nameplate nickel production and 32% of the expanded cobalt nameplate (53% of original cobalt capacity) were reported.

Major milestones:

Dec 1998	Leaching commenced in first autoclave
	Early leach extractions 83% Ni and 81% Co
Mar 99	First mixed sulphide produced and fed to refinery
	Three autoclaves operating
May 1999	First nickel produced, grade exceeded LME spec.
July 1999	First cobalt briquettes produced, grade above 99%
	Throughput 80% of design
July-Oct 1999	100 Day campaign
Dec 1999	Mechanical completion
	Expansion to 5000 t/a cobalt
Oct 2000	Nickel production 46% of nameplate

Problems encountered:

As with Cawse and Bulong, the basic process has worked satisfactorily, as evidenced by the early attainment of high metal extractions and high product purities. Significant design and materials problems have been encountered which have retarded progress in ramping up. It is understood that the main problems have now been addressed and ramp-up can now be accelerated. No fatal process flaw has emerged.

- Initial cracks in autoclave titanium lining welds. (Rectified satisfactorily.)
- Autoclave acid injection system was found to be inoperable, and injection tube material was inadequate. (Injection system was modified and tantalum tubes were installed.)
- Rapid erosion of ceramic defusers in bottom entry flash vessels occurred. (Upgraded materials and alternative designs did not sufficiently extend operating life, and leach temperature and throughput were restricted. Permanent solution was to convert all flash tanks to top entry.)
- Problems were experienced with knifegate valves and victaulic couplings. (Replaced.)
- Problems occurred with valves in the refinery. (Rubber lining upgraded and seals modified.)
- Problems were experienced with the slurry feed tanks. (Suitable agitators fitted.)
- A second mill classification screen had to be retrofitted.
- Corrosion and scaling occurred in the mixed sulphide precipitation circuit. (Materials were upgraded, descaling was carried out and a new improved rake was installed in the thickener.)
- Problems were experienced with the rubber linings in the CCD thickeners. (Linings had to be repaired.)
- Safety incident took place when 5 workers were affected by venting of hydrogen sulphide during a power failure.
- Hydrogen sulphide plant was debottlenecked to achieve desired capacity.
- Rectifications were required to steam lines and vent piping in the PAL area.

3. IMPLICATIONS FOR FUTURE PAL PROJECTS

A number of new PAL projects have been anxiously waiting in the wings during the commissioning and ramp-up of Cawse, Bulong and Murrin Murrin, their future obviously heavily dependent on the success or otherwise of the three WA plants. Although there is still some water to flow under the bridge, especially with Murrin Murrin, a number of implications have emerged at this stage.

- All three basic processes work.
- There does not appear to be a fatal technical flaw in any of them.
- Operating costs have yet to be firmly established.
- Material selection is clearly one of the most significant issues to address, and it is paramount that new projects learn from the experience of those who have gone before. Cost minimisation in this area is fraught with danger. Extreme care needs to be exercised during the preparation of detailed specifications for equipment, piping, valves, agitators etc, especially for the pressure leaching area.
- Saline water can be utilised successfully, provided that the additional corrosion is properly addressed, and efficient measures are taken to minimise undesirable carry-over to other process steps. Saline water can actually be a blessing for clayey ore, such as at Bulong.
- It would be prudent to stick with top entry flash tanks, and chokes need to be carefully sized.
- Scaling does not appear to be a significant issue in the leach autoclaves, but can cause major problems in other plant areas such as mixed sulphide precipitation, direct solvent extraction, ammonia re-leaching and desalination. Whenever there is a risk of scaling, provisions for regular clean-out such as by-pass piping or duplicate piping are sound investments.
- Close attention needs to be paid to the selection and installation of rubber, HDPE and other linings, especially in large items such as thickeners and mixer-settlers for which rectifications are expensive, time consuming and disruptive.
- Careful design and operating practises must be applied when using adjacent solvent extraction circuits involving different organic extractants to avoid carry-over from one circuit to another.
- Serious and disruptive problems can occur with “standard” support facilities such as steam boilers and water treatment plants. The design and construction of such facilities can be overshadowed by the apparently more demanding process facilities. Wherever feasible, standby capacity should be installed.
- Provision for separate stockpiling of different ore types to facilitate blending is advisable. Reasons for blending can include control of nickel or cobalt grades, mixing low and high acid consuming material and reducing the adverse effects of clayey ore by blending with more competent material.
- Generous surge capacity should be provided between each process step to enhance operability.
- The experience, skill and dedication of the operating and maintenance crews are vital to achieving a successful operation.
- Future operations ought to be able to improve upon the ramp-up times for Cawse, Bulong and Murrin Murrin. For a large plant a ramp-up time of 24-30 months is indicated from the commencement of leaching, while for a smaller facility 18-24 months should be attainable.

The Australian “dry” laterites have highly variable mineralogy and frequently contain significant clayey zones. Materials handling can be difficult, and settling densities low. On the other hand, “tropical” laterites such as at Moa Bay tend to be more consistent, easier to handle, lower in acid consumers and generally settle much better. Thus, in general, “tropical” laterites should be less demanding to process, and in some cases may lead to lower capital and operating costs.

4. HOW WILL FUTURE PAL FLOWSHEETS LOOK?

Simplified Bulong, Murrin Murrin and Cawse process flowsheets are shown in Figures 1, 2 and 3. Although differing in detail, the front end of each is basically similar. The main differences in concept lie in the nickel and cobalt recovery and refining steps:

- Bulong has adopted an innovative sequential direct solvent extraction process for cobalt and nickel. Nickel is recovered as cathode by electrowinning without an intermediate precipitation stage. Cobalt sulphide is precipitated after solvent extraction, and is treated in an on-site refining process to produce electrowon cathode. During the eight-year development period, various process alternatives were evaluated, and the direct SX route was selected as potentially the lowest cost option. The overall strategy was to use the initial single stream plant to optimise the plant design prior to expansion to a larger capacity. The economics of the initial operation were enhanced by treating high grade ore.
- The Murrin Murrin flowsheet is based on combining the commercially proven process used at Moa Bay, Cuba, for the precipitation of mixed nickel/cobalt sulphide with the refining technology used commercially by Sherritt in Canada. The adoption of an essentially proven process route was appropriate to minimise overall risk for the construction of such a large multi-stream operation.
- The Cawse flowsheet includes the precipitation of an intermediate mixed nickel/cobalt hydroxide precipitate, followed by a refining process utilising ammonia leaching, solvent extraction and electrowinning to produce cathode nickel. Cobalt sulphide is precipitated for sale. This route, using proven process “building blocks” used elsewhere in the industry, enabled Centaur to adopt a fast-track schedule while minimising risk and achieving competitive capital and operating costs. It also provided the option of marketing the intermediate precipitate. Like Bulong, the overall strategy was to build a single stream module operating on high grade ore first, to be expanded later. An ore upgrading step is included.

Although future projects will be aiming at minimising risk and achieving a shorter ramp-up time than the three existing operations, they will also be looking at process improvements to reduce capital and operating costs and increase operating efficiencies. This is can be seen from some of the flowsheets currently under consideration:

- Goro, New Caledonia: Inco have developed a novel direct solvent extraction process, which differs significantly from Bulong. A new organic extractant is used to simultaneously extract nickel and cobalt, which are subsequently separated in another SX circuit using proven technology. Nickel oxide is produced by pyro-hydrolysis, which is used commercially in other applications. Cobalt is precipitated as carbonate, though other forms could be made. Advantages of the Inco process are claimed to include the elimination of the cost for a pH adjustment reagent such as ammonia as used at Bulong, and a relatively simple cobalt production route. Inco have carried out extensive mini-pilot plant work in Canada, and are currently running a fully integrated pilot plant in New Caledonia.
- Ramu, PNG: This project has adopted a variation of the mixed hydroxide route, which uses inexpensive lime as the precipitant in place of the magnesia used at Cawse, in order to reduce operating costs. The other main difference is that the precipitate is re-leached with an ammonia/ammonium sulphate solution. Lime has been widely used commercially as a precipitant in cobalt production, and ammonium sulphate leaching followed by SX/EW of nickel was extensively piloted by the USBM in the nineteen seventies. Highlands have carried out pilot plant campaigns for Ramu.
- Ravensthorpe, WA: It has been reported that the current strategy being considered for Ravensthorpe is to produce nickel/cobalt hydroxide precipitate on site and transport it to QNI in Qld for refining in their ammonia leach operation, which would have to be expanded. Ravensthorpe also includes an ore upgrading step.
- Syerston, NSW: The flowsheet is based on producing a mixed sulphide intermediate for on-site refining as at Murrin Murrin. However, a different process has been adopted for the refinery, which uses magnesia in place of ammonia for pH adjustment, thus avoiding an ammonium sulphate by-product. Also, electrowinning is used instead of hydrogen reduction for metal production. The flowsheets provides for the recovery of a gravity platinum concentrate.

Some of the numerous other PAL projects at various stages of development include Young in NSW; NiWest, Kalpini and Mt Margaret in WA; Weda Bay and Gag Island in Indonesia; Prony and Nakety in New Caledonia; Nonoc, Rio Tuba and Mindoro in the Philippines; Ambatovy in Madagascar; and Vermelho in Brazil. Undoubtedly these projects will also be considering process improvements and innovations. Possibilities include:

- By-product scandium recovery (eg Young and Syerston).
- Indirect heat exchanges in place of direct contact vessels for preheating pressure leach feed.
- Use of high acid consuming ore to neutralise residual acid in the autoclave discharge to utilise the acid and reduce limestone consumption. This was piloted by Amax as part of their "Omniverous Process" in the nineteen seventies.
- Recovery of residual acid by means of solvent extraction, ion exchange or membranes, for recycle to leaching as a means of reducing overall acid consumption.
- Extraction of nickel and cobalt from PAL solution by resin-in-pulp to eliminate the expensive CCD thickeners. Alternatively, it could be considered for scavenging metal values from the CCD tailings to increase overall metal recovery and/or reduce the number of thickening stages.
- Replacement of mixer-settlers by pulsed columns in the various solvent extraction circuits to reduce cost, footprint area and organic losses.
- Elimination of labour intensive intermediate starter sheets in nickel electrowinning by direct deposition on to stainless steel blanks, as has been successfully introduced into copper electrowinning.
- Blending sulphide ore or concentrate with the PAL feed to generate acid and heat in the autoclave, which could offer capital and operating cost savings and possibly offer a profitable way to treat low grade nickel bearing sulphides.

5. THE PAL PROCESS IN THE BIG PICTURE

The following points are extracted from the Keynote Address at the ALTA 2000 Nickel/Cobalt Conference in Perth in May, given by Gordon Bacon, VP Engineering and Technology for Inco:

- "Most of the expansion in nickel production capacity in the next ten years will come from processing of laterite ores.
- Over the short term, capacity increase will occur by brownfield expansion of existing lower cost laterite smelters. However, this expansion is limited.
- Most of the expansion in nickel production capacity in the next ten years will come from laterite PAL plants.
- The capital cost requirements for a laterite smelter and a PAL plant are similar (in the range US $ 8-12 per pound of nickel annual production). However, with future improvements, it is more likely that PAL plants will be built at the lower end of this range.
- The cash operating expenditure for a PAL plant is generally lower than for a ferronickel smelter. This and lower energy consumption provide an economic advantage to the PAL process.
- The expected cobalt credit for PAL plants is limited due to projected low cost of cobalt over the next ten years (in the range US $ 5 and 10 per pound with US$7/lb as a likely cobalt price)."

Although nothing is ever certain in the mining and metallurgical industry, the PAL process appears poised to play a major role in the future production of nickel and cobalt. Much of the credit for this is due to the courage, determination and entrepreneurial spirit of companies such as Resolute, Preston, Anaconda and Centaur who were the driving forces behind the PAL plants now in operation in Western Australia.

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Fig 1.
Simplified Bulong Flowsheet

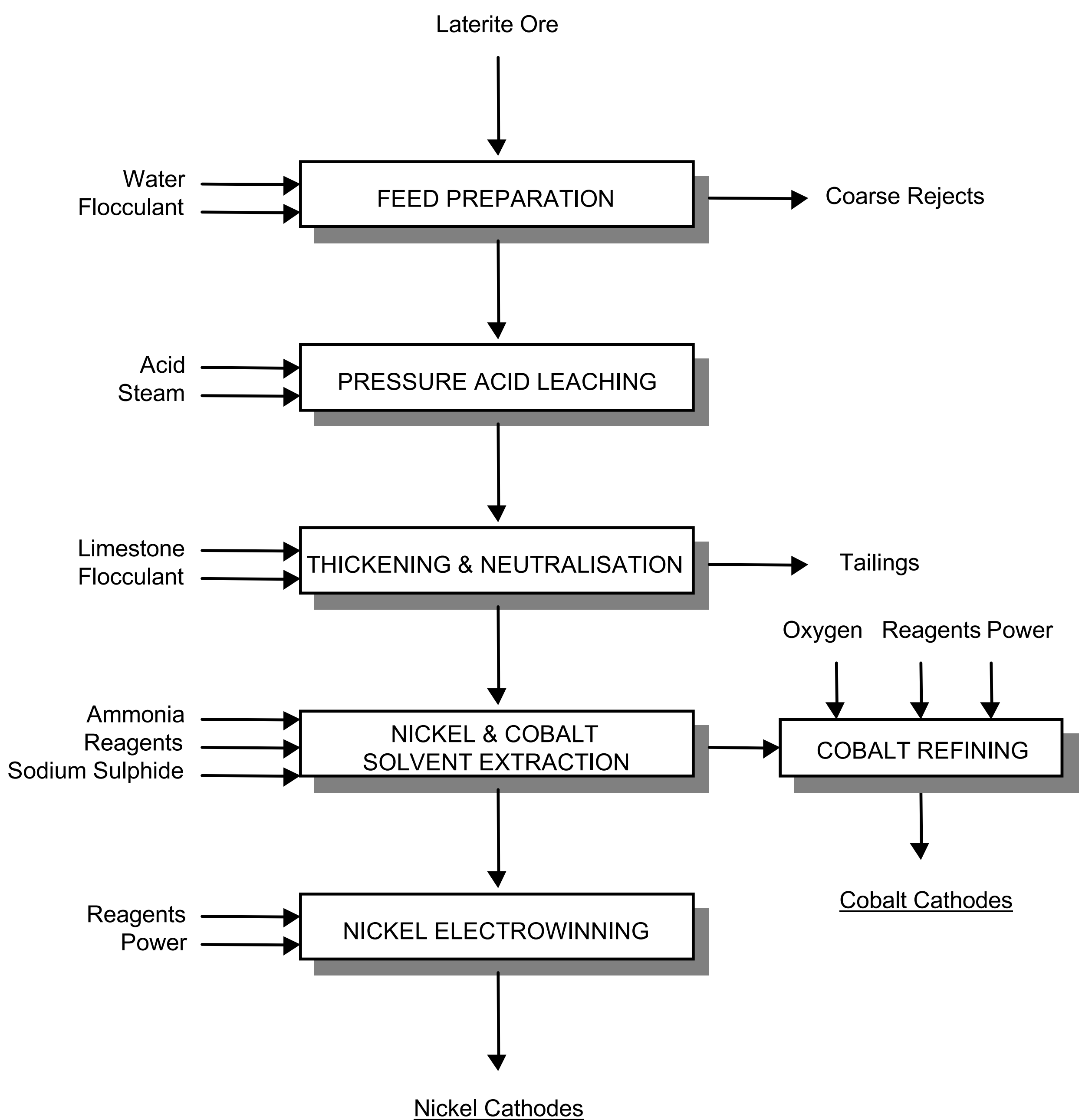

Fig 2.
Simplified Murrin Murrin Flowsheet

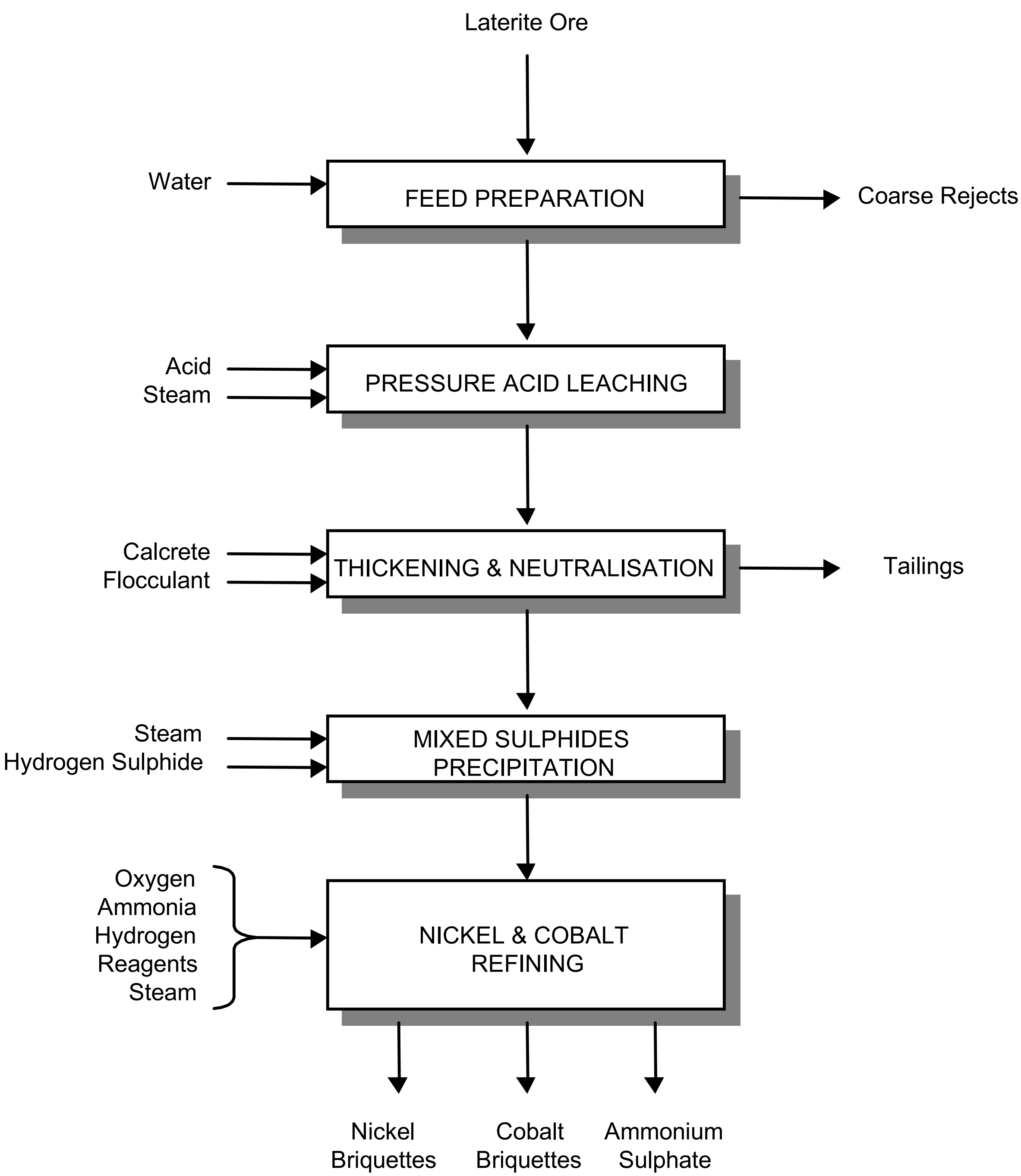

Fig 3.
Simplified Cawse Flowsheet