

THE IMPACT OF A CRUSHING PLANT UPGRADE AND DMS PRE-CONCENTRATION ON THE PROCESSING CAPABILITY OF THE TATI NICKEL CONCENTRATOR

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Abstract

The concentrator expansions at Tati Nickel Phoenix Mine that have increased the milling plant capacity from 3.6 to 5 Mtpa with a final overall plant design capability of 12 Mtpa are described.

In the initial years of operation, the plant could not achieve its nameplate capacity mainly due to its notorious micro-gabbro nickel ore reducing the availability and throughput of the crushing circuit. A new mine plan was adopted which extended the life of mine by reducing the cut-off grade, but had the consequence of requiring the concentrator to treat additional ore with a lower head grade.

Various projects were initiated to extend the concentrator throughput capacity – debottlenecking the crushing plant, installation of a new primary gyratory crusher and the introduction of a 1,600 t/hr pre-conc DMS plant which enabled the capacity of the milling circuit to be increased by 40% to 650 t/hr, due to the rejection by the DMS plant of up to 60% of the RoM ore.

Following laboratory tests and bulk sample pilot plant testwork at Mintek, a 200 t/hr demonstration DMS pilot plant was built which successfully demonstrated the pre-concentration principal. The main project was then initiated by installing a new primary gyratory crusher to receive the increased RoM. The crusher feeds a secondary-tertiary crushing operation followed by feed preparation and separation of the (25 x 1)mm size fraction in four parallel DMS processing modules and treatment by the existing enhanced milling and flotation plant.

A review of the DMS testwork is given which shows the remarkable impact of the pre-concentration stage on the expanding the overall throughput capacity. This in turn has significantly extended the life of mine, allowing it to reduce the cut-off grade and curb the previously selective mining practices.

Mine Status - Early 2005

By early 2005 the Tati Nickel Phoenix mine and concentrator (*ref. Figure 1a*) had been operating for about two years, but it was not achieving its design throughput for any sustained period. DRA Mineral Projects, based in Johannesburg, were invited to review

the potential for improving the plant capacity to 4 Mtpa and to determine any limitations in the process at the same time.

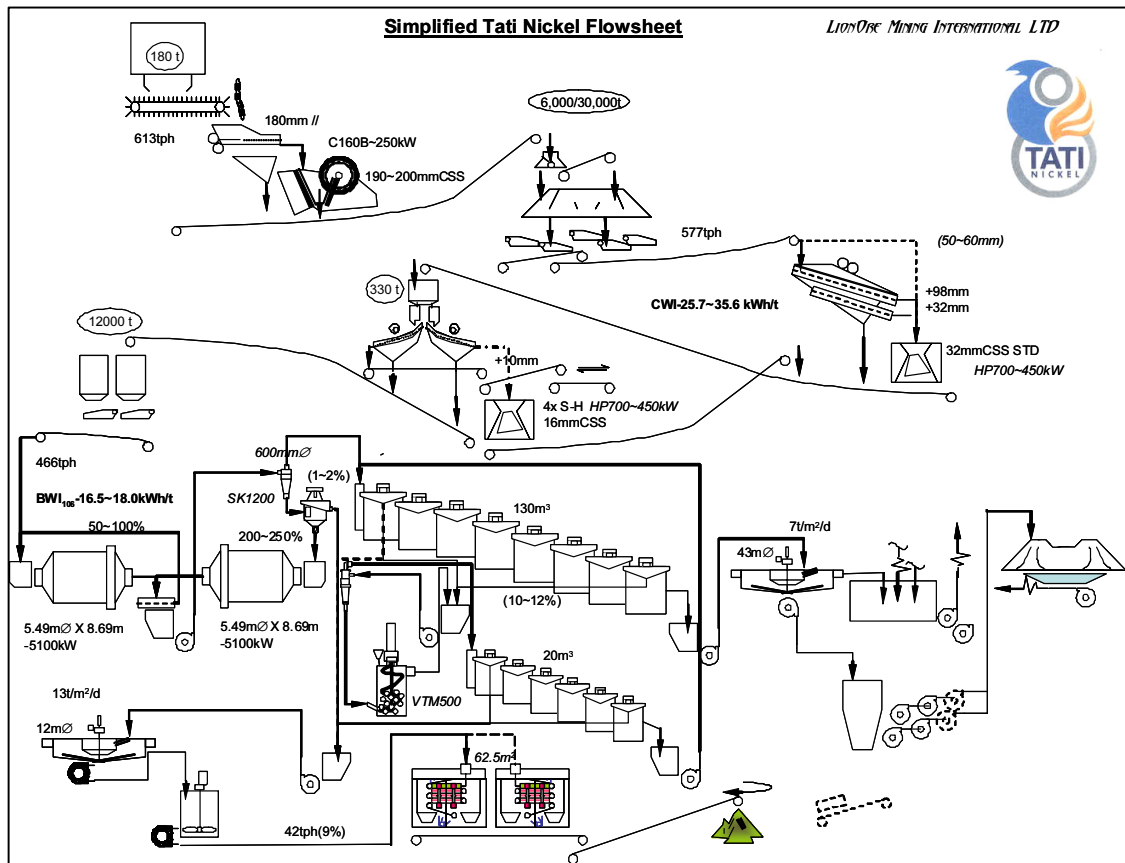


Figure 1a-Overall Plant Flowsheet

At the same time in order to extend the life of mine and increase the nickel units produced, the Mine was assessing and re-defining the mining plan. The selected plan proposed to increase the Phoenix mine reserves by lowering the cut-off grade from ~ 0.25 %Ni to 0.2 ~ 0.15 %Ni, which in turn resulted in the concentrator having to treat additional tonnage at lower head grades.

Due to the extremely hard and abrasive nature of the disseminated nickel-copper sulphide micro-gabbro; the Metso C160 primary jaw crusher closed-side setting was relaxed from a design 130mm up to 190~200mm, in order to alleviate chokes and stalling problems associated with slabby ore 'tombstones'. The knock-on effect was a significant coarsening of the expected feed to the secondary and tertiary crushing circuit.

Following a review of the production statistics, it became apparent that the concentrator re-design should mainly focus on improving the performance of the crushing and milling circuits, rather than the downstream processes.

The milling-flotation circuit (*ref. Figure 1b*) had been operating at a nominal 470 tph, with limited incursions beyond this apparent threshold value. Unfortunately, no tenable grind-recovery relationships could be derived from the plant metallurgical

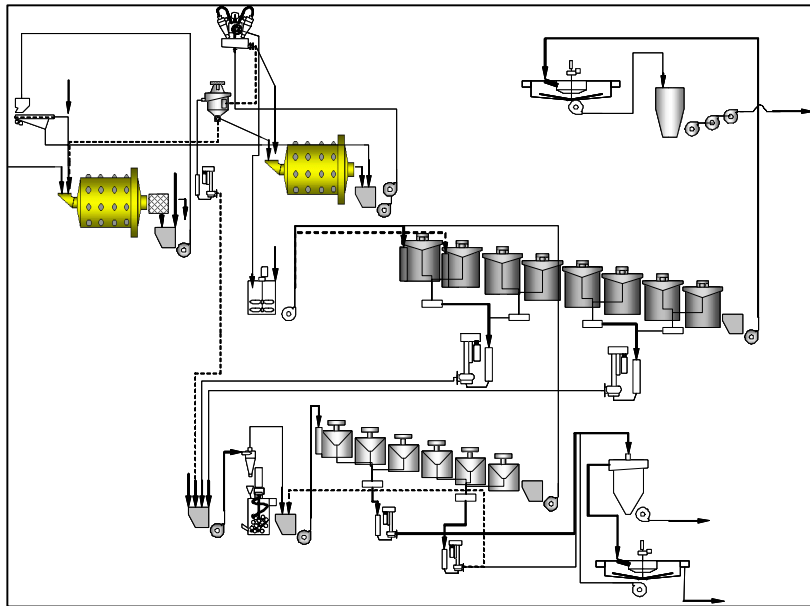


Figure 1b-Original Plant (Milling & Flotation)

results due to unsteady operations. However, it was possible to determine the ore comminution variability (which generally follows grade variation) and it was found that preferential grinding was taking place. The mill circuits were then simulated by population balance modelling techniques using DRA ‘in-house’ model parameter derivations and Excel-VBA computer models.

Concentrator ‘Stress Testing’

Although the crushing circuit had already been identified as a throughput constraining step, a “stress test” of the milling circuit was run to determine its limitations and to try if possible, to obtain a grind-recovery relationship.

A concerted effort was put into filling the mill silos ahead of the test campaign, so that the true capacity of the primary and secondary milling circuit could be ascertained without running out of similar -12mm feedstock. Care was taken to prepare this bulk sample in terms of what the future ore would be. The two-stage ball milling circuit was sampled at known feed rates in order to assess the grinding performance, and to develop

discrete-size population balance simulation models that could reliably describe the milling process for a typical low-grade Phoenix Pit ore.

The primary mill feed rate was increased in increments from 525 tph up to 600 tph and samples were taken following 4 hours of stabilization. The ore specific breakage rates at each throughput increment were determined and the breakage characteristics were found to be similar to the historical mine performance data. The primary and secondary milling 'stress test' modelled the breakage rates providing reasonably consistent results (*ref. Figures 2 & 3*).

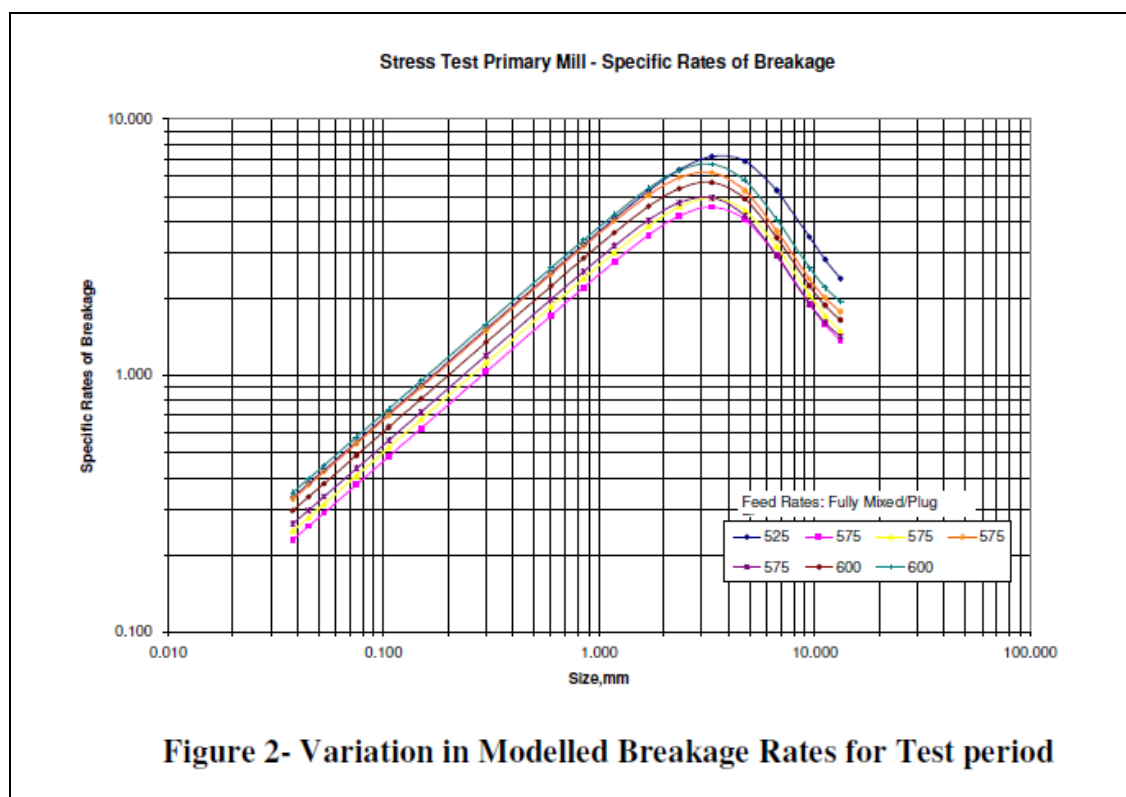
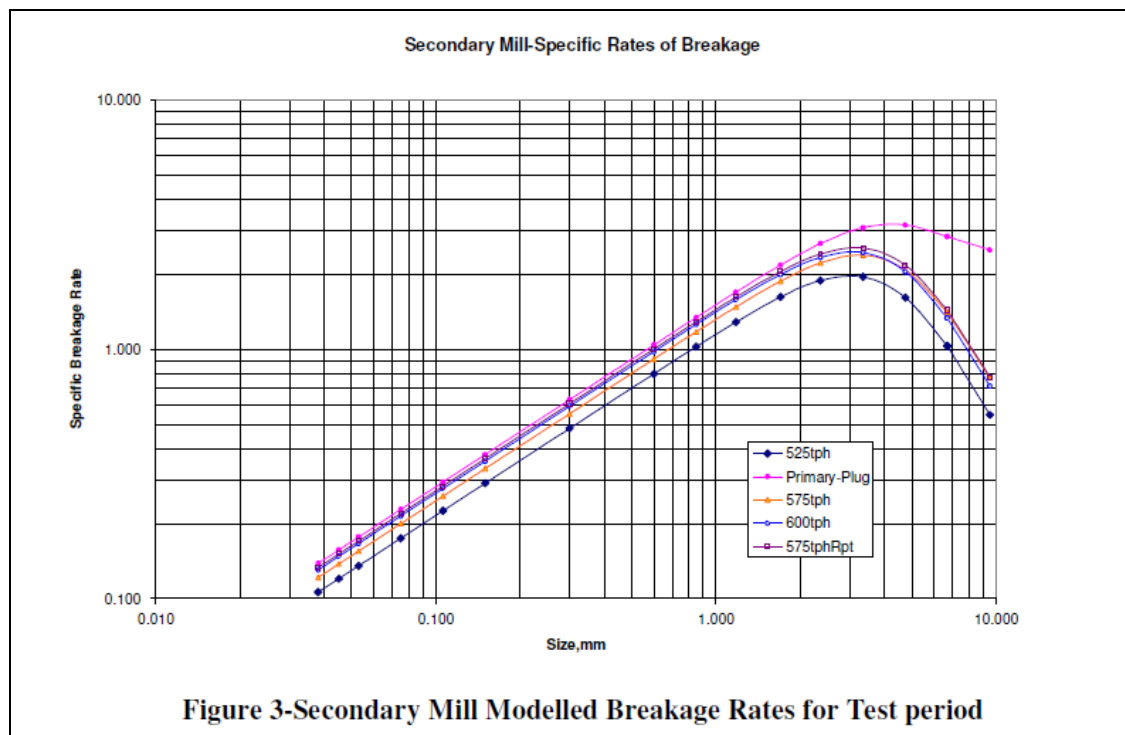


Figure 2- Variation in Modelled Breakage Rates for Test period



A single milling classification screen was used for the first ramp-up tests, two screens for the 600 tph and repeat 575 tph tests. A combination of 6 mm and 4.5 mm aperture screens were used in order to broaden the recycle fraction's size distribution to the primary mill, improve progressive grinding and reduce the effect of 'pip' surges. As the primary milling circuit only had a 4.5 min cycle residence time, the performance of the primary mill was quite difficult to simulate satisfactorily because of the oversize effect influencing the flow through the mill. Modelling of the upper sizes with respect to mill discharge distribution, responded better to a plug-flow model compared to a fully mixed single-reactor model. The secondary mill behaviour was found to be satisfactorily modelled by three fully-mixed reactors in series, which is regarded as normal.

It was therefore determined from the field test work, that the plant could achieve a nominal 625 tph on a steady state basis. It was also noticed that the primary screen oversize had a lower grade than its feed, due it was inferred to preferential grinding. The rejection of this fraction may also increase fresh mill throughput even further.

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Modelling of the current milling circuit configuration (mills in series) also indicated that it was relatively self-compensating and contributes a further 2 % by mass of $-75 \mu\text{m}$ to the mesh of grind, when compared to a parallel mill circuit.

Concentrator Upgrade (Project 5M)

The design requirements of the concentrator upgrade could now be cost assessed, given the limitation of the throughput capability of the milling circuit.

Firstly the necessary improvements to the crushing circuit in order to sustain an annual throughput of 5 Mtpa were assessed. A trade-off study using various crusher simulation models revealed that a second jaw crusher station and a common open-circuit secondary crusher (*H8800-600kW*) ahead of the ROM stockpile would improve the crushing plant delivery rate and the performance of the tertiary crushing circuit (*ref. Figure 4*).

Secondly the flotation circuit was upgraded on a pro-rata basis, in order to treat the higher process flows. The cleaner circuit was bolstered by two large high mass-pull / high lip-length cell units (*Model Type OK50TC*) at the head of the bank in order to reduce the flows into the existing cells (*ref. Figure 5*). A later addition to the flotation plant was the reconfiguration of the cleaner circuit to produce two separate concentrates and an increase in the concentrate filtration capacity to 700 ktpa. This was prompted by the announcement of the Activox Project and possible outsourcing of the smelter contracts, given the threatened closure of BCL at the time.

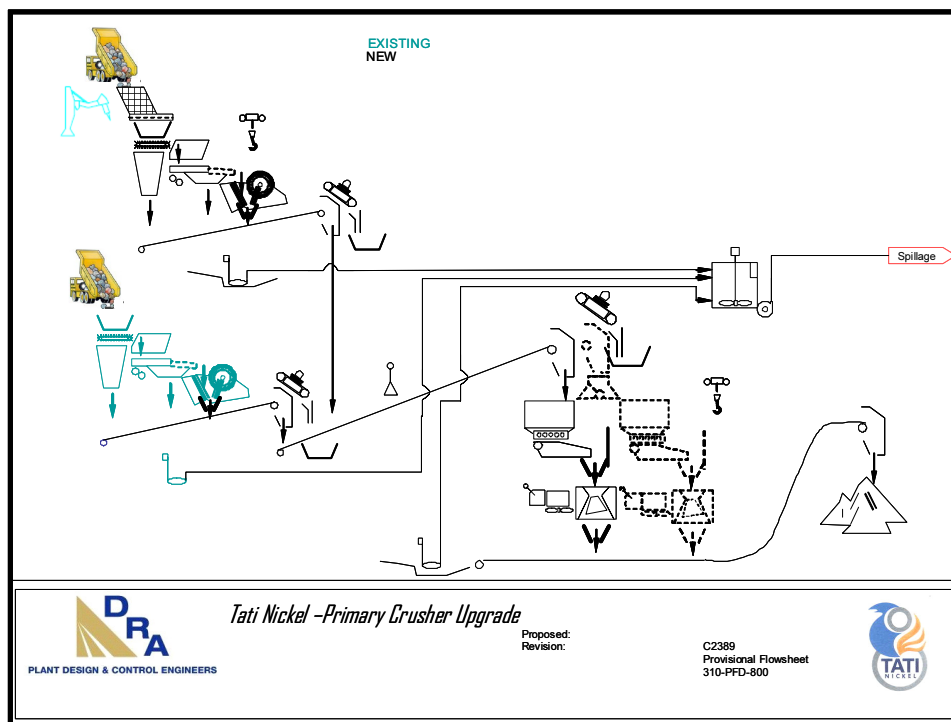


Figure 4 Project 5M Primary/Secondary Crushing Upgrade

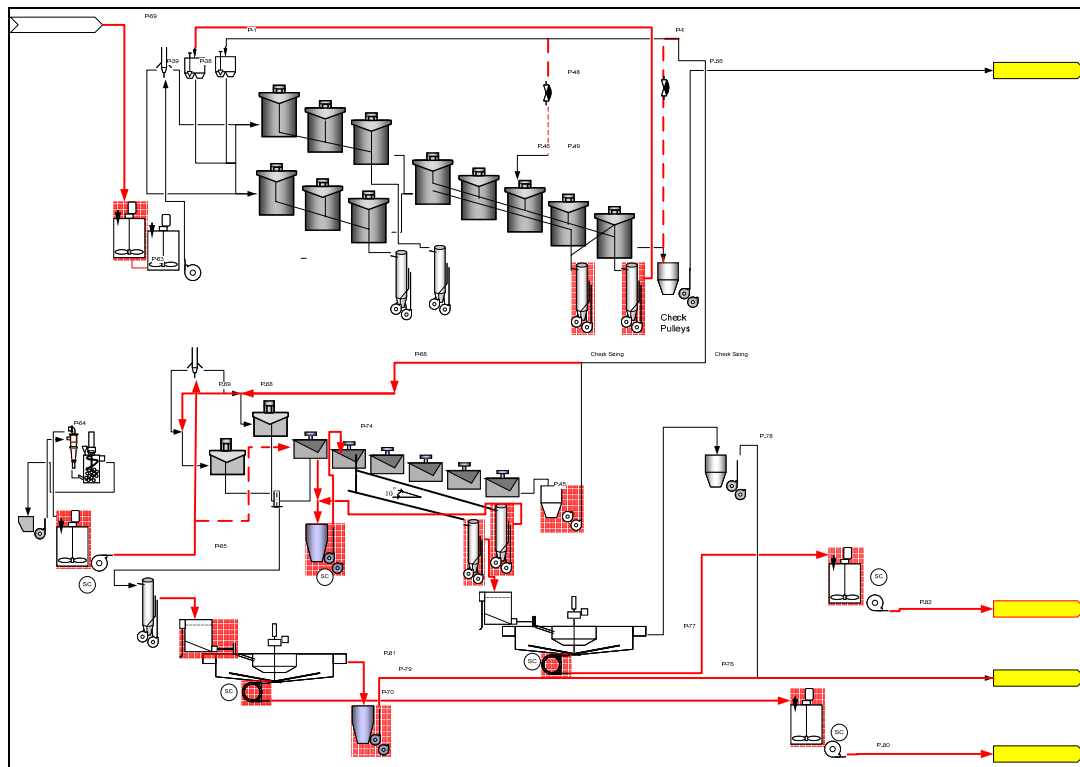


Figure 5 Project 5M & Flotation Section High-Low Grade Split Cleaner Upgrade

Thirdly it was proposed to increase the primary mill power draw by converting it from an overflow to a semi-grate discharge. This modification however did not go to plan. The liner change did not go smoothly and after several disastrous overloads including liner damage incidents, it was decided to abandon this method and revert back to the original overflow discharge configuration.

The secondary mill, as a consequence of the limited power on the primary mill, operated in a “teetering” / overload condition most of the time. However the expected grind-recovery relationship was maintained at a 5 Mtpa throughput rate.

DMS Testwork and Demonstration Plant

As the mine cut-off grade was reduced, it became necessary to investigate the possibilities of a pre-concentration stage ahead of the ‘uprated’ concentrator.

Following the observation that preferential grinding was taking place, it was speculated that the ore may respond well to a dense medium separation (DMS) process. Heavy liquid tests on various grade and ore types from the Phoenix Mine were conducted at the Mintek laboratory, Johannesburg. The samples tested were split into (20 x 10)mm and (10 x 1)mm size fractions prior to DMS and a densiometric analysis derived between SG’s 2.7 and 3.2.

The mass and sinks recovery relationships (ref. Figures 6a, 6b & 6c) show a potential to recover 85% of the Nickel in a sinks fraction whilst rejecting 60 % of the feed mass at a separation density of 2.95 – 3.0 t/m³.

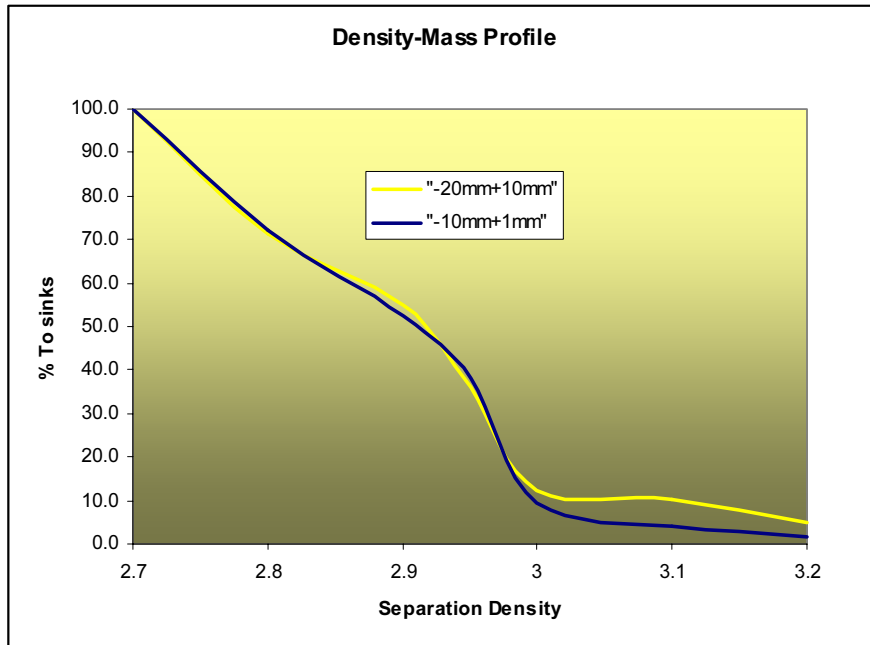


Figure 6a - DMS Testwork Results – Sinks Mass vs. Density

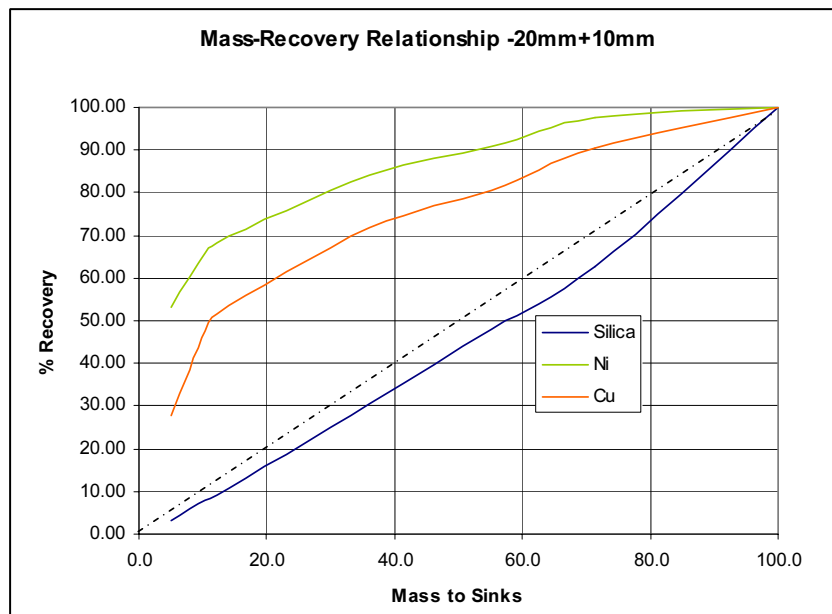


Figure 6b - DMS Testwork Results – (20 x 10)mm Sinks Ni Recovery vs. Mass

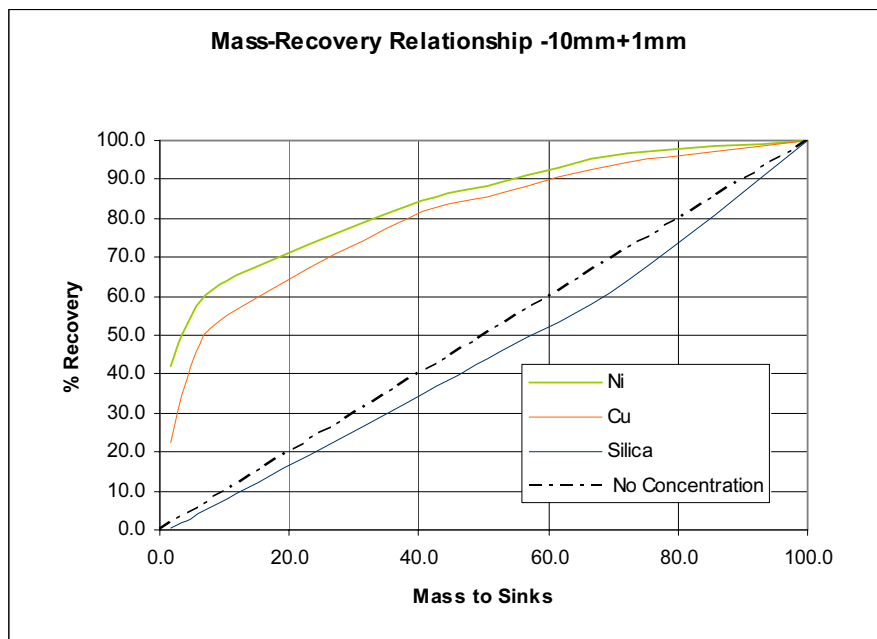


Figure 6c - DMS Testwork Results – (10 x 1)mm Sinks Ni Recovery vs. Mass

Following this a bulk sample was pilot tested and gave promising results in line with the bench scale results. For the low grade ore, it was found that up to 59 % by mass of the RoM could be rejected with a rejects grade similar to the concentrator flotation tailing.

The final stage before implementing a full size plant was to build a ‘demonstration’ 200 tph DMS plant treating the (20 x 1) mm size fraction at the mine. This plant used some of the old equipment from the Selkirk magnetic separation plant.

Unusually high “epm” values of 0.065 to 0.07 at a D_{50} of SG 2.95~3.0 cut-point were experienced at times (*ref. Figure 7*) thought to be due to the FeSi medium contamination by pyrrhotite. The epm values are expected to improve to 0.026~0.032 in practice following the incorporation of a pyrrhotite bleed and flotation unit in the circuit.

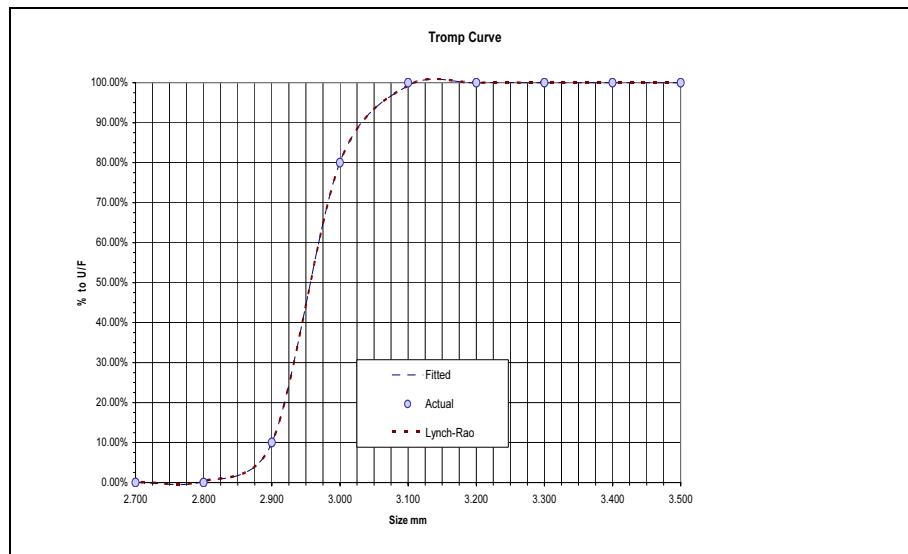


Figure 7 – Demonstration DMS Plant in-situ tracer test Tromp Curve

The demonstration plant operated satisfactorily despite an interesting development: Due to batch processing the pyrrhotite build up in the medium, the ferrosilicon began to corrode giving off hydrogen gas which caused a minor explosion during a plant shutdown. Measures were then put into place to control the medium pH and provide a pyrrhotite bleed in order to avoid further occurrences.

Tati DMS - Expansion Project

Having proved the viability of a DMS pre-concentration step on an industrial scale, Tati Nickel embarked upon an ambitious plan to expand the crushing and pre-concentration circuit capacity up to 12 Mtpa, in order to feed the 5 Mtpa milling and flotation plant. Phase I of the project was to treat 8 Mtpa RoM, while a future expansion to 12 Mtpa would continue to increase the life of mine and lower the cut-off grade. The recommended circuit is shown in *Figure 8*.

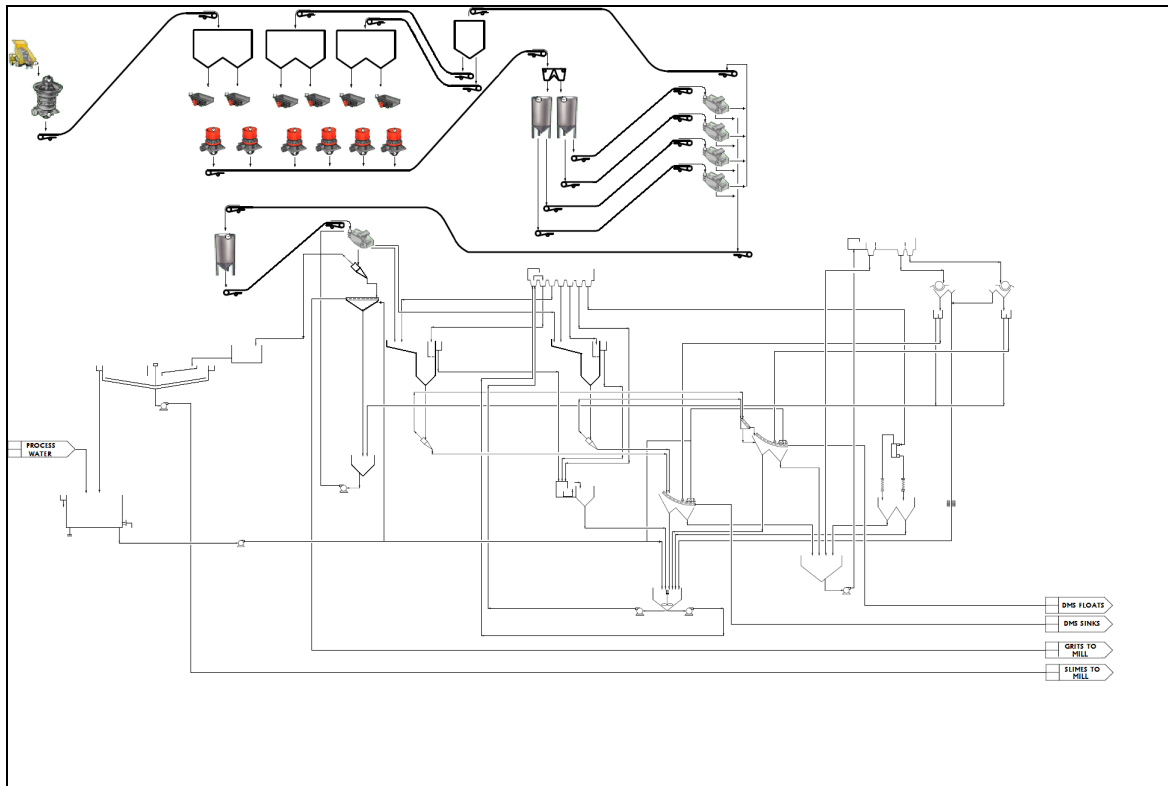


Figure 8 Simplified Expansion Flowsheet – Crushing & (DMS x 4) Flowsheet

A trade-off study clearly showed that a 2,600 t/hr capacity gyratory crusher was the best solution to receive RoM from the pit. Open-circuit secondary crushing (in a similar fashion to the Project 5M preparation circuit) ahead of closed-circuit tertiary crushing, could then produce -25mm DMS feedstock.

A full scale pre-concentration DMS plant was designed, constructed and commissioned using four parallel modules treating up to 400 tph each, giving a total DMS capacity of 1,600 t/hr. Detail plant design drew heavily from DRA's experience in designing DMS pre-concentration plants for UG2 platinum ores and each module has a single-stage gravity feed DM cyclone configuration using "banana" feed prep, drain & rinse screens, hi-strength counter-current magnetic separators and automatic density control by water addition into the circulating medium.

The slimes and fine ore fractions from the feed preparation stage is collectively introduced to the primary milling circuit. Temporary stockpiling of grits and slimes in a thickener serves as intermediate storage whenever the main concentrator is down.

The DMS sinks product was reintroduced to the existing tertiary (now renamed the 'quaternary') closed-circuit crushing circuit where it forms the majority of (-10 to 12)mm mill feed which is stored in the existing mill silos. The existing jaw crushing circuits are

used for preparing any high-grade ore arisings and stockpiled ahead of the quaternary crushing circuit.

Gyratory Crusher Design

Kawasaki was awarded the contract to custom-design a primary gyratory crusher for the notoriously hard Tati ore (which ranks in the top ten hardest ores ever tested by the JK Tech Drop weight test). The 60"Ø gyratory crusher (*model KG15026 EHD-S*) was designed by Kawasaki after stringent testing at their Earth Technica facility in Japan (*ref. Figure 9*).

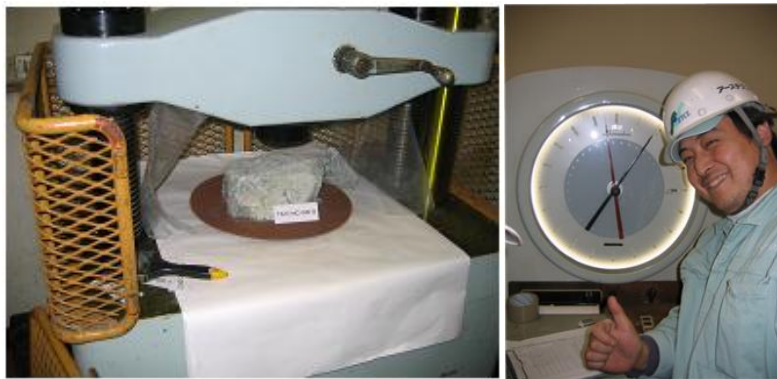


Figure 9 –Testing at ECTL Japan [the sample shown required 47mt force to break] compared with an 84~100 MPa typical fracture requirement

Three major rock types Gabbro, dolerite and granite, were sent for specific rock mechanic and crushing tests to ascertain their breakage characteristics for 1m³ equivalent lumps, the crushing power requirements and the optimum chamber nip angle. As a result it was decided to use a 1 MW motor for the crusher, despite the fact that the estimated average consumption would be about 690~730 kW in order to ensure that the crusher would not stall. The Kawasaki crusher was successfully commissioned achieving the design requirements and at times justified the need for a 1 MW motor.

It is interesting to note that this crusher is only the third 60"Ø x 1MW gyratory crusher in the world; the other two being a FL Smidth model at Anglo American's PPRust North (Mogalakwena) Platinum project and a Metso crusher for Assmang's iron ore BKM project.

Upside Potential

Following the successful commissioning of the gyratory crusher and the DMS modules, it may be possible for the crushing section to operate 'off-peak' and thus significantly reduce the operating power costs for the plant.

Conclusions

The capacity of the Tati Nickel 3.5Mtpa concentrator which treats one of the hardest ores in the world, has been successfully increased from 3.5 Mtpa to 12 Mtpa. This has significantly lengthened the life of mine and simplified the mining operations.

All the changes to the existing conventional crushing, milling and flotation plant have been introduced following computer modelling and testwork consisting of laboratory,

pilot and demonstration plant in the case of the DMS plant. The major plant changes have seen the introduction of a new 60" dia primary gyratory crusher, a 1600 t/hr DMS pre-concentration plant which rejects 60 % of the RoM ore and minor changes to the existing milling flotation plant. Due to the change in mill feed as a result of the DMS plant rejecting 40 % of the RoM, the circuit capacity has increased from 470 to 650 t/hr.

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