MILESTONES IN THE IMPROVEMENT OF CONCENTRATOR NICKEL AND COPPER RECOVERIES AT BCL

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Abstract

BCL operates a conventional three-stage base metal concentrator to treat run-of-mine (ROM) nickel (Ni) and copper (Cu) ore. Currently, approximately 3 million tonnes of ROM is processed annually at head grades of about 0.71% Ni and 0.65% Cu to produce about four hundred and fifty thousand (450K) tonnes of Ni/Cu concentrate containing about 3.0% Ni and 3.2% Cu. The plant was commissioned in 1973. Available metallurgical performance data shows Ni recoveries gradually declined from around 85% in 1980 to about 78-80% in 1995-96.The reasons for the decline appear to have been related to ageing of the plant and equipment as well as declining nickel grade in ore. The first major intervention to reverse this adverse trend in recoveries came in 1996 with installation and commissioning of a $100m^3$ capacity Outokumpu tank cell with the aim of performing secondary scavenging of the tailings from the Agitair scavenger bank. This was followed by the replacement of old Agitair rougher and scavenger banks in 1999 with Wemco 144 cells. Millstar grind and Floatstar flotation control systems were introduced in 2001/2002 as part of continuous improvement initiatives geared towards improving Ni recoveries. The circuit was reviewed and modified in 2002 to incorporate a new combined cleaner bank comprising $6x50m^3$ capacity Outokumpu tank cells, which replaced four separate Agitair cleaner banks (rougher cleaners, scavenger cleaners, magnetic cleaners and sand cleaners). All these initiatives contributed to a reversal of the decline in Ni recoveries and saw them restored to levels of 83-86% beyond 2002.

Currently, a number of projects, including use of alternative reagents, grind optimisation and a holistic flowsheet review are underway with the objective of improving Ni recoveries and grades. The objective of this paper is to give a historical perspective of the recovery improvement initiatives implemented over the last thirty-five years (1973-2008), and summarises projects planned for the medium to long term that are geared towards improving the metallurgical performance of the BCL concentrator in terms of grade/recovery.

1 Introduction

The BCL concentrator was commissioned in 1973. A review of the available historical data dating back to 1980 shows that, the actual flotation nickel recoveries declined steadily compared to the expected or standard recoveries that were achieved in the past with the same ore and concentrate grades. Nickel recoveries achieved in the 1980s averaged 85% and declined to around 78-80% in the 1990s (Figure 1).

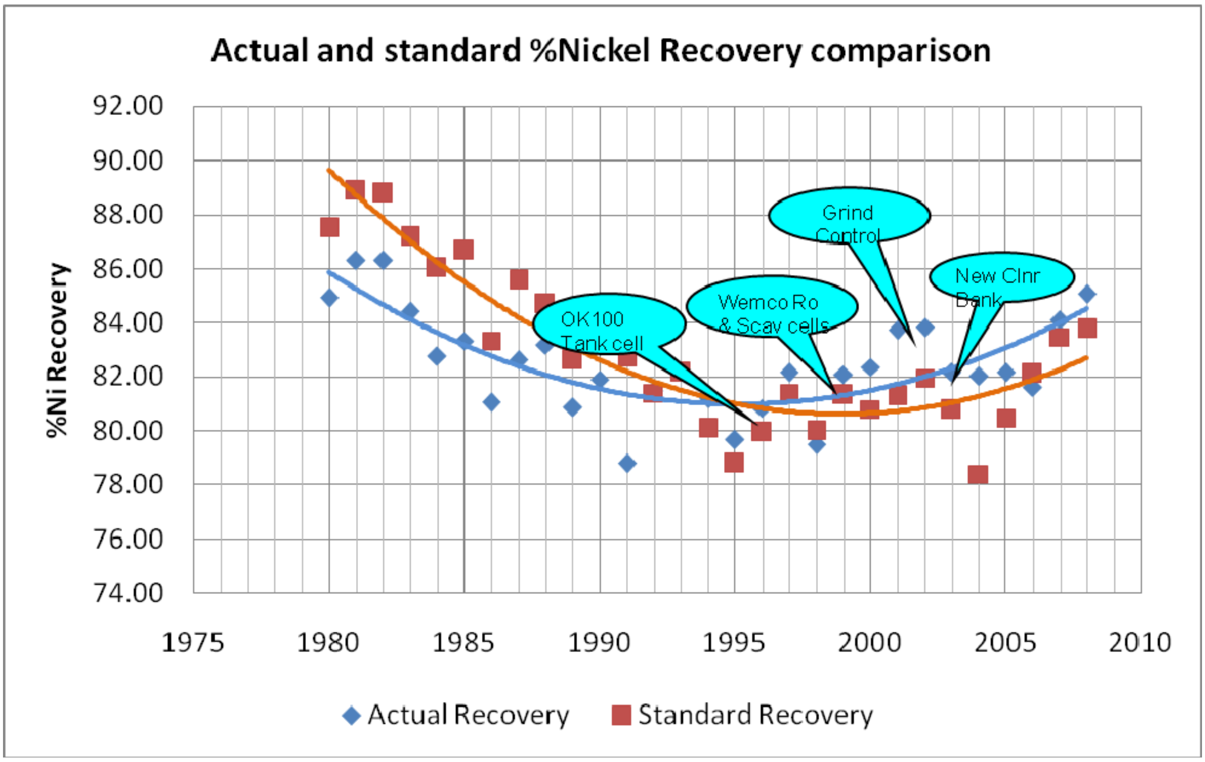

Figure 1: Shows drop in the actual nickel recovery against the standard recovery

The continued downward trend in the plant performance necessitated the need for interventions as this impacted on the company bottom line. To that effect, technical and operational investigations into reasons for poor plant performance were instituted. The investigations revealed that poor mechanical condition of old plant equipment and lack of continuous process efficiency improvements contributed to this downward trend in the nickel recoveries. The loss in nickel recovery was further affected by the fact that the smelting capacity required high mass pull feed input at an optimal concentrate grade, whilst at the same time the ROM ore nickel grade was declining as shown in figure 2 below. As a result, BCL management embarked on these interventions aimed at reversing the declining plant recoveries, ensuring that recoveries were improved and sustained.

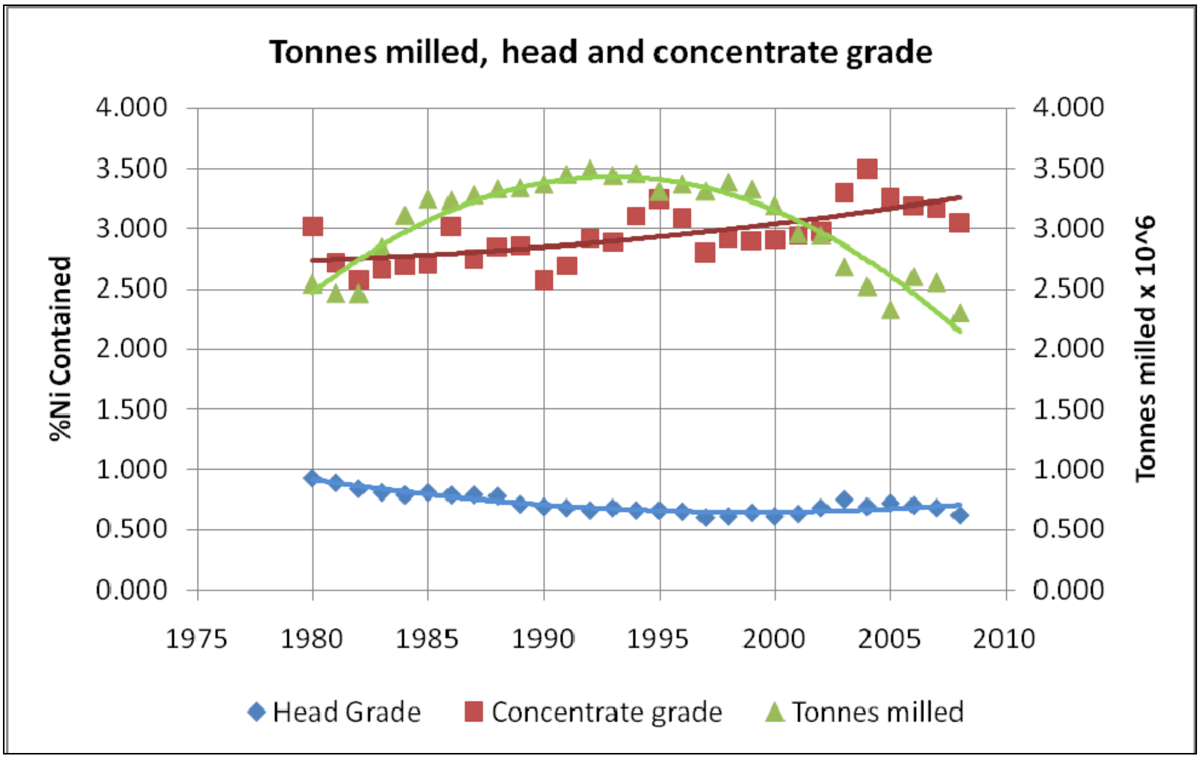

Figure 2: Shows variation of head grade, final concentrate grade and tonnes milled

2 Description of the intervention programme

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In 1980, the capacity of the Smelter to treat new concentrate was increased by 50% thereby necessitating the Concentrator flowsheet to be modified in order to optimize nickel and copper recoveries. This had the effect of producing a low grade high mass pull concentrate. This was achieved mainly by the installation of wet drum magnetic separators to recover the weakly magnetic pyrrhotite (which has 0.10 % Ni "locked" as fine grained pentlandite) from the rougher bank tailings. Testwork conducted at that time clearly indicated that this approach was more favorable than increasing flotation capacity by adopting copper sulphate and / or acid activation of the pyrrhotite. Furthermore, the inclusion of magnetic separators in the rougher and scavenger circuits improved both sulphide and magnetite recoveries.

The increase in actual nickel recoveries resulting from the interventions to be mentioned below are calculated as follows:

$$\%Ni\ Recovery = \frac{(f-t) \times 100\%}{(c-t)} \times \frac{(c)}{(f)} \quad (1)$$

Where:

f = %Ni in feed,
c = %Ni in final concentrate and
t = %Ni in final tails.

The standard recoveries are based on the historical plant performance achieved with the same feed grade to the flotation circuit. Therefore the Standard recovery is calculated as shown in equation 2 below.

$$\text{Standard \%Ni Recovery} = \frac{M}{(a \times M + b)} \qquad 2$$

Where:

$$M = \frac{(f-t) \times 100\%}{(c-t)}$$

and a and b are recovery factors associated with a various feed grades.

The values for a and b in equation 2 above are determined from a plot of the inverse of enrichment ratio (c/f) against mass pull denoted M above. The value of a is the gradient while b is the intercept. The standard recovery curves for various feed grades are then determined from a plot of Standard %Ni recovery (Equation 2) against mass pull. The standard recovery curves thus generated are the ones that are compared to the actual recovery for the same feed grade.

The following major milestones in the intervention programme were also implemented successfully:-

- Installation and commissioning of 100m^3 Outokumpu flotation tank cell in 1996 resulting in nickel recovery improvement of 0.20 %,
- Replacement of rougher and scavenger flotation banks in 1999 by adding 12 % additional flotation capacity,
- Millstar and Floatstar for process control of the grinding and flotation circuits in 2001/2002.
- Replacement of Agitair cleaner banks with 6 x 50m^3 Outokumpu flotation tank cells.

This section discusses the interventions that were undertaken in order to improve the nickel recoveries.

2.1 100m^3 Outokumpu Tank Cell in December 1996

A review of the mineralogy by CSIRO consultants showed that the nickel recoveries could only be improved by pyrrhotite and pyrite recovery whose distribution in ore is shown in Table 1 below. The nickel losses to tailings occurred in pyrrhotite, pyrite and the coarser size fractions.

The pyrrhotite and pyrite are slow floating minerals requiring additional flotation residence time. Outokumpu was engaged to explore the potential of improving the nickel recovery. The study revealed that the potential lay in the extension of flotation residence time with an envisaged 1% increase in nickel recovered. This justified the installation of the flotation tank cell.

Table1. Mineralogy of BCL ore and concentrate

		Feed		**Concentrate**	
Mineral	**Composition**	**Mass %**	**Contained %Ni**	**Mass %**	**Contained %Ni**
Pentlandite	$(FeNi)_9 S_8$	1.7	0.61	7.1	2.57
Chalcopyrite	$CuFeS_2$	2.0	--	6.2	--
Pyrrhotite	$Fe_7 S_8.Fe9S_{10}$	24.1	0.1	69.3	0.26
Pyrite	FeS	1.0	0.004	3.0	0.014
Magnetite	$Fe0.Fe_2 0_3$	2.5	--	1.0	--
Gangue	Various	68.7	0.01	13.4	0.003
Total		**100**	**0.72**	**100**	**2.85**

Outokumpu designed and manufactured a $100m^3$ flotation tank cell to scavenge the Agitair scavenger tailings. The $100m^3$ Outokumpu flotation tank cell was installed and commissioned in 1996 at a cost of BWP1.5 million. This allowed the recovery of slow floating nickel associated with pyrrhotite and pyrite minerals. Only a 0.2% increase in nickel recovery was achieved compared to 1% envisaged due to the challenges encountered with the placement of the tank cell in the circuit. The economic analysis is shown in Table 2. The tank cell presented challenges to the commissioning team with regards to its placement. It was initially used a rougher, which proved to be costly as chalcopyrite was fast floating compared to pentlandite resulting in significantly high copper recovery and grade in concentrate at the expense of the nickel. Placement of the tank cell at the front end of the circuit and owing to the aging mechanical condition of the balance of the circuit resulted in inferior metallurgical performance.

2.2 Replacement of Agitair rougher and Scavenger flotation banks with Wemco flotation cells-September 1999

The rougher and scavenger flotation cells had been operating since the plant was commissioned in 1973. The structural integrity of the flotation cells housing and mechanical condition of the flotation cells had deteriorated and, affected stability of the operations due to frequent repairs on these units with a resultant loss of recovery. In order to improve the nickel recovery, the condition of the two critical flotation banks warranted their replacement as they were beyond the economic life and compromising plant recovery. In December 1997, a project was initiated to replace the banks with Wemco cells. The new Wemco 144D cells were procured and installed in 1998/9 at a cost of BWP10million. This resulted in significant improvement in nickel recovery of 0.9% and stable plant operations. The combined annual savings realized on maintenance and labour costs were of the order of P0.45 million. Cost benefits realized are shown in Table 2.

Other benefits which came as a result of this improvement are as listed below:

- The central control room was introduced for operators to control the plant remotely which marked the first concentrator plant automation.
- There was flexibility in the rougher bank operation as the new flotation cells allowed the high grade concentrate of the fast floating pentlandite and chalcopyrite in the first three cells to be sent directly to the final concentrate bypassing and without overloading the cleaning stage.
- Better flotation stability due to improved residence times as a result of increased cell volume of the Wemco cells and level control.

2.3 Grind and flotation circuit control-2001/2002

Grinding performance is critical to flotation performance. Therefore, control of the grinding circuit is paramount as any upset in grinding operations adversely affect flotation performance. Mintek in Republic of South Africa was contracted to supply and install Millstar software package to monitor and control the grinding operation. Prior to installing the Millstar software package the grinding circuit was controlled manually and after installing Millstar the following were achieved:

- Grind control was automated with adjustments to mill feed, mill power draw and inlet water controlled remotely.
- Installation of variable speed drives (VSDs) on mill feed conveyors and cyclone feed pumps so as to control circuit product size by varying feed tonnage and cyclone feed pressure.
- The PSI (Particle Size Indicator) and PSE (Particle Size Estimator) were also installed to further stabilize the grind size variability by predicting cyclone overflow size and acting quickly on sump level and pump speed to minimize changes on cyclone flow and hence stabilize the circuit.

More work to improve the grind was done in 2002 to optimize the crushing section with the objective of presenting finer ore feed to the milling section. Eventually all screens were changed from square aperture to slot type to cater for all size configurations of the ore particles and the crusher gap settings were also reduced. This resulted in the finer feed being presented to the milling circuit at a P_{80} of 11.2mm from the original 12.5mm.

The flotation circuit control was automated using the Mintek Floatstar software package. This comprised:-

- Floatstar level stabilizer which takes into account the upstream disturbances of the flotation cell and makes appropriate adjustments to the downstream cells to absorb the effect of the disturbance before it propagates throughout the flotation stream. This obviated the manual control of pulp levels.
- Floatstar flow optimizer which optimizes the level of the sump that feeds the cleaner circuit and the feed flow to the same cleaner circuit.

These installed control systems made the stabilization of the flotation circuit operations easier and good results were achieved (0.3% increase in absolute nickel recovery). Both sets of software were supplied and continue to be serviced by Mintek.

2.4 New Cleaner circuit

In order to produce a final concentrate suitable for the smelter, and retain maximum flexibility with regard to the grade of the final concentrate produced, it was necessary to review and modify the complicated flotation flow-sheet in the cleaner circuits, Figure 2a. The cleaner circuit comprised of four conventional Agitair cells flotation banks which operated poorly partly due to the old equipment and lack of flexibility in operating the circuit to produce the desired metallurgical efficiencies. In 2002, a decision was made to replace the cleaner banks with Outokumpu flotation tank cells. The objective was to improve the nickel recoveries and also reduce maintenance costs of the old cleaner cells.

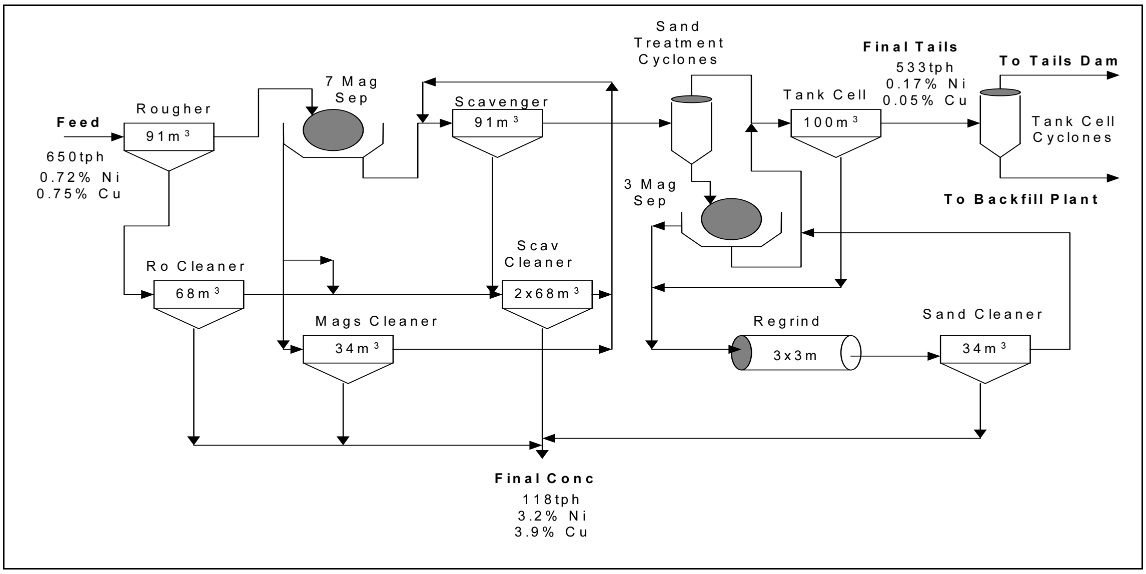

Figure 2a. Flowsheet with four separate cleaner banks

A bank of 6 X 50 m^3 capacity tank cells were installed and commissioned by Outokumpu in December 2002 at a cost of BWP 6.9million. The flow sheet is shown in Figure 2b. The cells operate in series with a provision for bypass and to run either the first three or last three tank cells depending on the circumstances situation. This improved the nickel recovery by an additional 0.9%, and concentrate grade of 3.0-3.5% nickel was achieved.

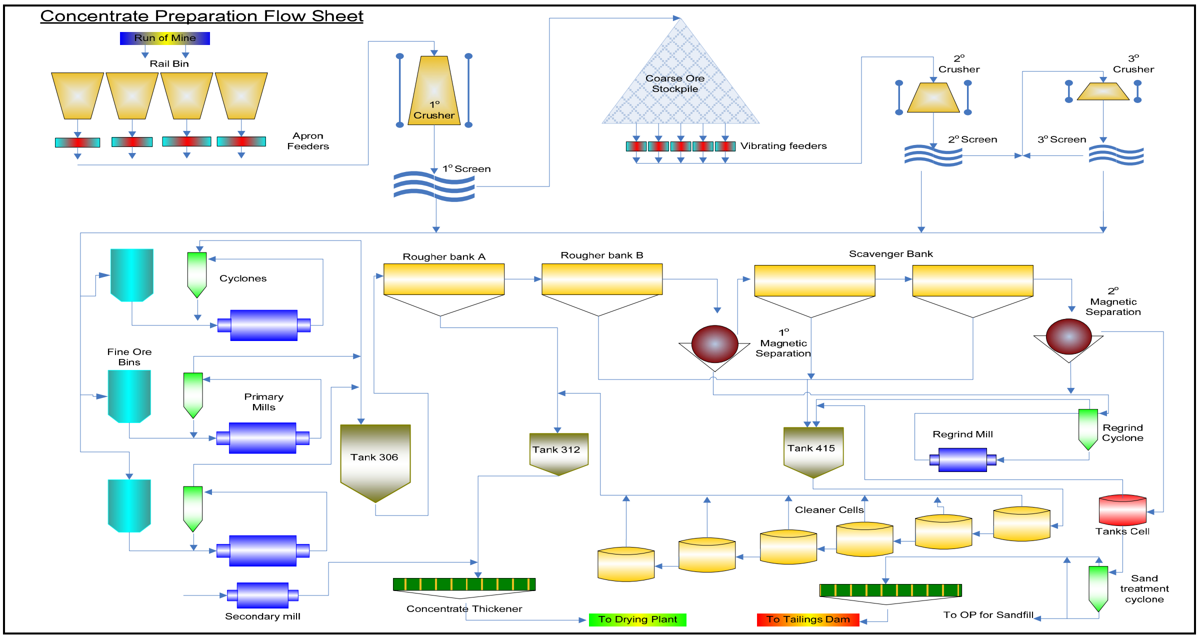

Figure 2b. Concentrator flowsheet with tank cells

The feed to the cleaner circuit is a mixture of concentrates from the last four rougher flotation cells, scavenger bank cells, 100m^{3}tank cell and the magnetic concentrate from the regrind mill.

The concentrate from the cleaner tank cells are combined together with the concentrates from the first three rougher cells and are pumped to the thickeners as final concentrate whilst the tailings stream is re-circulated to the head of the scavenger bank.

A 200m^3 conditioning feed tank with variable speed drives and tramp screening facility were interposed between the milling and flotation circuits. This offered surge capacity, improved conditioning times and flexibility of operation of the flotation circuit as flow surges were eliminated.

3 Economic Analysis

Table 2 below shows the economic benefits analysis for the above process interventions undertaken by BCL Limited. The projects contributed additional profit of BWP46.5 million annualized due to these increase in nickel recovery. The new cleaner bank yielded the highest return on investment when the initiatives are compared at normalized conditions of tonnage, selling price and exchange rate. The calculations were done for each option from the time of implementation to end of 2008 and the monetary benefit annualized.

Table 2. Economic/benefit analysis

Milestone	% Ni Rec Increase	Tons	Conc Ni	Smel R	GMV	Ni (t) for Rev	Ni lbs	US$/lb	US$	P/$	Ni Revenue P (10^6)	Capex P (10^6)	Profit/ Loss P (10^6)
Tankcell	0.2	154279	309	90%	70%	194.391	427660	4	1710640	5.01	8.6	1.5	7.1
Ro&Sc	0.9	112343	1011	90%	70%	636.987	1E+06	4.53	6348208	5.22	33.1	10.0	23.1
Grind/Float Ctrl	0.3	54250	163	90%	70%	102.533	225572	5.83	1315087	4.78	6.3	2.0	4.3
New Clnr	0.9	54250	488	90%	70%	307.599	676717	5.83	3945260	4.78	18.9	6.9	12.0
i = US$ 3/lb & US$1 = P3.5											66.9	20.4	46.5

4 Other works done

Figure 1.0 shows that between 2003 and 2006 the recoveries were on another negative trend. During this period the concentrator was forced to pull for high concentrate to create space for treatment of toll and reclaim material. Also there was a demand for high grade concentrate by the Smelter. The actual recoveries however still remained higher than the standard recoveries except for 2006. Also the plant was not operating steadily because of deteriorating plant structures. A decision was taken at the end of 2006 to rehabilitate plant structures through the structural integrity project. In June 2008 the capacity of the sump feeding the cleaner circuit was doubled, followed by another sump for the tank cell feed at the end of 2008. These initiatives added some stability to the flotation circuit and thus improved recoveries to 85% at the end of 2008.

In addition to the above intervention works undertaken, a lot of work has been done at laboratory scale also aimed at improving the nickel recoveries. Such works include the following:-

- Regrind of rougher and cleaners tailings studies
- Regrinding cleaner feed to P_{80} of 38micron. This was found to increase the selectivity of the cleaner flotation stage
- Regrinding of final tailings to 80% minus 75 microns showed increase in flotation response and high recoveries for the tailings.

However, implementation of these finer grind improvements await downstream modifications to avoid increased dust losses at the drying plants.

5 Future work

- Alternative reagents with the objective of enhancing metallurgical efficiencies and cost effectiveness.
- Dense media separation. Pilot test results revealed that the nickel grade can be upgraded by a factor of 1.5-2.
- Replacement of rougher and scavenger banks with flotation tank cells. This should reduce the operating maintenance costs and improve residence time and recovery.
- Installation of an On-stream analyzer for process control and reagent addition optimization and possible labour reduction.

6 Conclusions

The initiatives embarked on by BCL management reversed the downward trend on nickel recoveries and restored the recoveries to levels of 83-86%.
The interventions helped the company realize operating profit of about BWP46.5million. There was improvement in the stability and flexibility of the operation of the plant.
It is expected that further improvements will be realized as initiatives currently being considered are implemented.

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