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Evaluation of the Blue Cube MQi Slurry Analyser for application in an advanced control system for the optimisation of a Gold Sulphide flotation circuit

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ABSTRACT

The Blue Cube MQi Mineral Quantifier Inline instrument uses reflective light spectroscopy and advanced chemometrics to measure mineral or elemental grade in a slurry line. The instrument takes scans continuously and sends data to the DCS or PLC control system.

Controlling the concentrate grades on a flotation circuit using low frequency measurements can be difficult or impossible, especially on a circuit that has fast process dynamics. The ability to rapidly measure changes in grade makes it possible to continuously manipulate the flotation circuit operating parameters such as level, airflow and reagent addition setpoints to optimise plant performance throughout changing conditions.

At Barrick's Porgera mine in Papua New Guinea the flotation circuit feeds sulphide concentrate slurry to a pressure oxidation circuit. In order to maximise gold recovery in the flotation plant and increase performance in the pressure oxidation process, there is a stringent requirement to maintain a stable and optimum sulphur grade. The gold recovery is directly affected by the sulphur grade as most of the gold at Porgera is sub-microscopic and associated with the sulphides (disseminated pyrite).

Porgera considered various points in the flotation circuit for installing Blue Cube analysers. This was part of a plant upgrade to improve process control. Due to budget constraints it was decided to initially only install one Blue Cube analyser on the final concentrate stream of the flotation circuit measuring sulphur, sulphides, gold and particle size. The accuracy of the calibration results were very good for all these properties. The sulphur measurement was used in an advanced control system to optimise and stabilise the grade. The paper presents comparisons between mineral grades determined using analytical laboratory analyses and the online Blue Cube data measurements, as well as benefits achieved by measuring grade online. An analysis of the plant data before and after installation of the Blue Cube and the advanced process control upgrade indicate that the flotation recovery increased by 1.98%.

INTRODUCTION

The Porgera deposit is located in Enga Province of Papua New Guinea (PNG), at elevations between 2200m and 2700m above sea level which is approximately 130km, north-west of Mount Hagen and 600km north-west of the national capital, Port Moresby. The Porgera mine is 95% owned by Barrick Gold Corporation, the other joint venture partner is 5% owned by Mineral Resources Enga Limited (a consortium consisting of the Enga Provincial Government and the local landowners). The Porgera process plant consists of a crushing and milling circuit with gravity separation using Knelson concentrators for separating the free gold, a flotation plant feeding the pressure oxidation circuit, cyanide gold leaching with carbon in pulp, and electro-winning.

Part of the gold in the Porgera feed ore is associated with sulphides such as pyrite, pyrrhotite and arsenopyrite. This gold is entrapped in the sulphide mineral matrix and can be recovered by flotation of sulphides. The only efficient way of releasing and recovering the gold is by breaking down the sulphides before leaching. In the case of Porgera this is done by pressure oxidation followed by cyanidation using carbon in leach (CIL) and carbon in pulp (CIP) (Weir, 1986).

In order to ensure full conversion of the sulphides, the autoclave reactor at Porgera operates at temperatures above 198 °C and pressures above 1750 kPa. These temperatures are achieved by controlling the oxidation rate of the exothermic sulphide reactions. Conditions such as feed rate, sulphide grade, slurry density and oxygen flow rate all influence the rate of oxidation while the temperature in each of the compartments is controlled by addition of quench water.

Having real-time online measurements of the sulphide in the flotation concentrate can help steer the plant in the right direction, whilst maintaining maximum gold recovery. Depending on conditions in the pressure oxidation circuit, sulphide requirements can vary but most often is maintained around 14%. Various process parameters are available for controlling the sulphide in the final concentrate; these include level, air and reagent addition in the 5 flotation banks.

Unlike many other online measuring devices such as XRF and NMR, Blue Cube is capable of measuring all elements including low atomic number elements such as sulphur, sulphides, carbonates, as well as slurry properties such as density and particle size. Blue Cube is also unique in that it provides continuous readings which is essential for efficient process control, since it provides readings that are much faster than the dynamics of the process, thus making it possible to rapidly react and stabilise the circuit to a desired condition (Mantsho, 2012).

PROJECT BACKGROUND

In 2011 Mintek (South Africa) conducted a feasibility study to determine the possibility of introducing advanced process control to the Porgera Concentrator. The study highlighted that Porgera's process flow diagram was highly interactive in terms of process dynamics, with a number of control objectives from different flotation sections strongly affecting each other, and ultimately the performance of the downstream pressure oxidation process. Process control on a system with this many interactions was difficult with the use of conventional PID controllers but could be achieved through using advanced control methods.

In the early days, in-stream analysers (ISA) were used to measure the sulphur grade online, but were at times inaccurate as the sulphur grades were not measured directly, but inferred from the iron concentration. Four of the most critical flotation streams that had the ISA installed were flotation banks 2 and 3 feed, flotation banks 2 and 3 rougher 1 concentrate, flotation bank 4 roughers 1 and 2 and scavenger 1 combined concentrate and the final concentrate streams.

It was decided then that, as an initial trial, the Blue Cube MQi in-stream analyser would be installed in the combined final concentrate stream after the transfer pump box before the pressure oxidation plant as shown in Figure 1.

The main objective was to determine the instrument's suitability for advanced process control. More specifically the instrument had to reliably produce online grade measurements that adequately captured the dynamics of the process, so that a control system could use the measurements to maintain the target sulphide and gold recovery. For this evaluation the instrument was calibrated to measure sulphur, sulphides, gold and % passing 38μm particle size.

INSTALLATION AND SETUP

Besides the requirement to verify the final concentrate grade achieved by the flotation circuit, the initial position of the Blue Cube analyser was also chosen due to ease-of-installation (requiring minimum mechanical modification for installing the analyser).

The main components of the Blue Cube analyser are shown in Figures 2 & 3 and consist of the following:

a) an optical processor containing a spectrometer;

b) a scan head mounted onto a custom made spool section with flanges to connect into the pipeline. The scan head and poppet sampler connects onto this spool section. The scan head has a sapphire glass window which is in contact with the slurry stream. Two optical fibres for transmitting and receiving light connect the scan head to the optical processor. For protection, these fibres are housed in a hydraulic hose and in order to ensure the quality of the light spectrum the fibres have a maximum length of 1.2 meters;

c) a poppet sampler is used for taking calibration samples and works in conjunction with the Blue Cube calibration scans;

d) a communications gateway which connects Blue Cube to the internet for remote access;

e) a data processor which contains the calibration sets is used for processing the optical data and determining the mineral grades; and

f) an interface box which is used to connect the Blue Cube outputs to the plant control system.

Usually Blue Cube is installed directly on the main pipe but in this case, due to ease-of installation, it was installed on the discharge of a sampler used for collecting shift composite samples located at the pump discharge.

The Optical Processor was positioned one meter from the scan head on an elevated platform close to the sample line. The Data Processor, Interface Unit and Communications Gateway were positioned on a frame diagonally across from the final concentrate tank.

CALIBRATION

Blue Cube uses chemometric methods to calibrate the optical spectra by comparing calibration scans with known compositions of samples taken at the same time. During calibration it is important to capture the full extent of the mineral variation. Remote access to the analyser is used to download the optical scan data as well as upload the calibration sets onto the instrument. The initial Blue Cube calibration commenced during the commissioning phase at Porgera and this occurred over a three week period in May 2013.

The result of the initial calibration as shown on a scatter plot in Figure 4 and compares the Blue Cube sulphur grade with those analysed in the laboratory. The accuracy of the calibration set was extremely good; having a root-mean-square error of 0.93 and an R^2 value of 0.86 (an R^2 value of 1.0 is a perfect fit). The sulphur trends of Blue Cube and laboratory values, as shown in Figure 5, also displayed a tight correlation between the two sulphur trends.

Initially Blue Cube was calibrated to measure several other variables, but these were not a priority to the plant, as they were not used in any advanced control strategy, and hence subsequent calibrations of those measurements ceased. A comparison of the gold and percentage passing 38µm size between laboratory analysed results and Blue Cube are shown in Figures 6 & 7, respectively for the initial calibration. These trends also indicate a very good correlation, in particular the gold, where the Blue Cube measurements were closely following the laboratory results for the range from 10 ppm to over 40 ppm.

Blue Cube relies on a good calibration to produce accurate measurements. The calibration is therefore updated once a month to ensure that it remains relevant to any new type of ore that may enter the plant. An outlier indicator (OI) is available as an output from the instrument and indicates when the instrument detects mineral or ore type not previously captured in the calibration set. This prompts the plant operators to take some calibration scans and samples.

DATA ANALYSIS

Calibration samples were collected and analysed to compare the data with assays from the laboratory. A comparison of sulphur data is shown over a period of six months in Figures 8 and 9. Absolute error values with and without a data filter (1st order exponential filter on consecutive samples to visually show how the error is trending over time) is also presented. The instrument showed good correlation over the period with measurements improving over time as is evident from the decreasing error values. On average, the absolute difference between the Blue Cube and the laboratory was 1.3% as shown in Table 1.

An analysis of the plant data before and after installation of the Blue Cube and the advanced process control upgrade indicates that the recovery increased by 1.98%. The normalised increase in gold recovery due to flotation circuit stability after the upgrade was 1.58% as shown in Table 2 and on Figure 10. A statistical analysis indicates there was minimal influence on the recovery from variations in feed grade, residence time, particle size and mineral liberation, ore types and lithology. The increase in gold recovery was mainly related to overall circuit stability enhanced by the process control system using real-time online sulphur measurement from the Blue Cube.

BENEFITS ASSOCIATED WITH BLUE CUBE

The biggest benefit of the Blue Cube is that it provides real-time online measurement trending, which allows the operators, or the process control system, to react quickly to changing plant conditions. The 15 second measurement updates enables the process control system to maintain a consistent sulphur grade in the flotation concentrate that is fed to the pressure oxidation circuit.

At times the measurements drifted a little, but since this happened over time, it was easily compensated for by offsetting the grade setpoint (in the controller) with this consistent bias.

Since commissioning of the Blue Cube MQi, the uptime of the instrument has been almost 100%, except during plant shutdowns.

Another significant benefit associated with the upgrade has been the reduction in steam requirement from the boilers for controlling the autoclave temperature. This has resulted in a drop in fuel usage by 2.4%, as shown in Figure 11. Usually, fuel usage is high with variable sulphur grades but is low at consistent grades as the autoclaves do not require steam to maintain the oxidation reaction.

CONCLUSIONS

The Blue Cube analyser was installed on the final concentrate line of the flotation circuit where it was successfully calibrated to measure sulphur, sulphides, gold and percentage passing 38 µm particle size. More specifically, the integration of real-time sulphur grade measurements with an advanced control system made it possible to stabilise the flotation circuit and optimise the feed sulphur grade to the pressure oxidation plant. This ultimately resulted in improved gold recovery in the flotation circuit as well as increased performance and reduced boiler fuel usage in the pressure oxidation plant.

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FIGURE CAPTIONS

FIG 1 Overview of Porgera flotation circuit

FIG 2 Blue Cube Installation: a. Scan Head, b. Optical Processor, c. Poppet Sampler

FIG 3 Blue Cube Installation: d. Communications unit, e. Data Processor, f. Interface Box

FIG 4 Initial Calibration scatter plot of the total sulphur data: Blue Cube data versus lab data (RMS-Error of 0.93)

FIG 5 Sulphur comparison between laboratory and Blue Cube measurements

FIG 6 Gold comparison between laboratory and Blue Cube measurements

FIG 7 Percentage passing 38μm comparison between laboratory and Blue Cube measurements

FIG 8 Blue Cube and laboratory comparison for sulphur showing absolute error for samples 60 – 250.

FIG 9 Blue Cube and laboratory comparison for sulphur showing absolute error for samples 250 - 420.

FIG 10 Gold recovery in the flotation circuit pre- and post-upgrade.

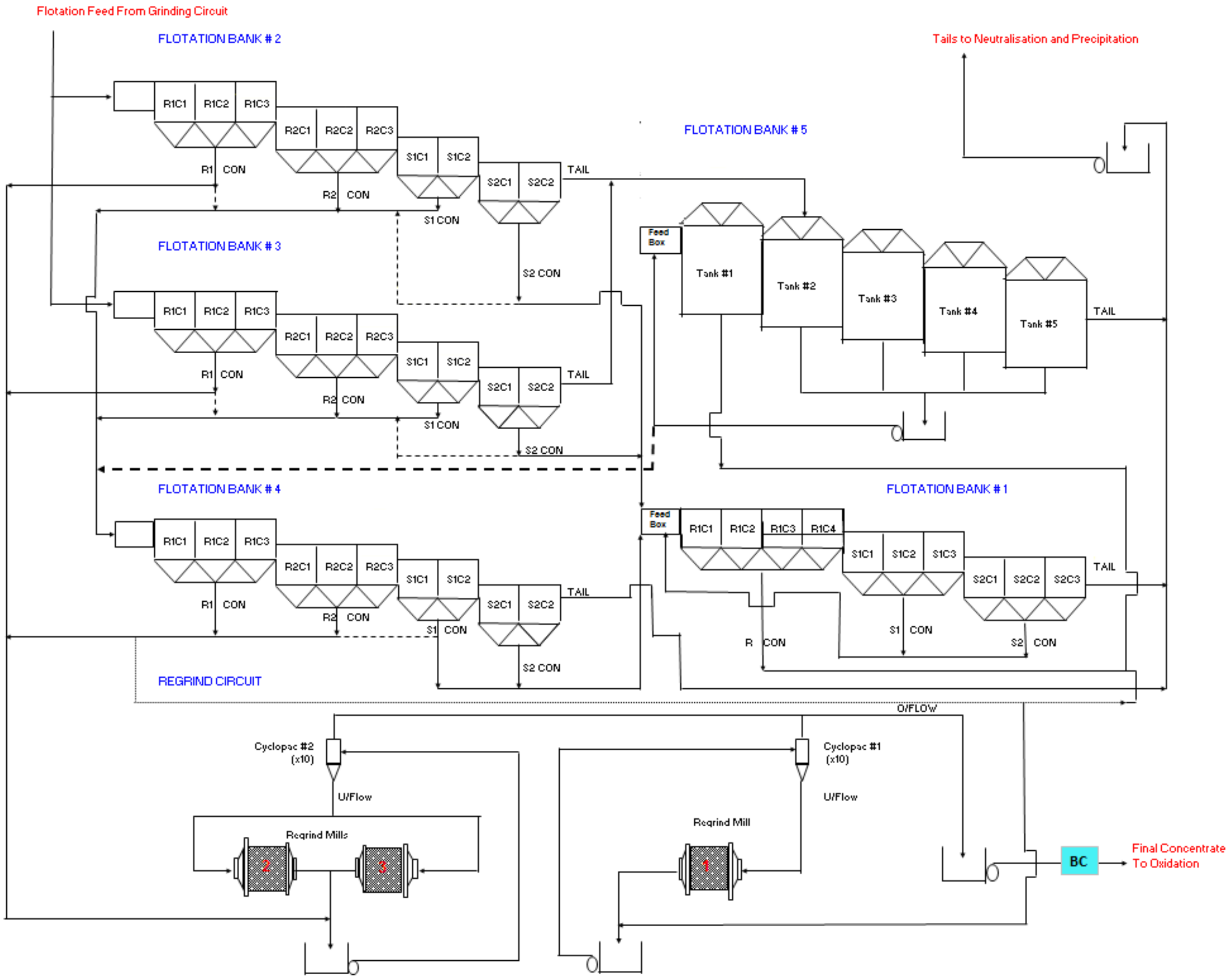
FIG 11 Diesel usage in the pressure oxidation circuit, pre- and post-upgrade.

TABLE CAPTIONS

TABLE 1 Difference between Blue Cube and Laboratory data

TABLE 2 Normalised Flotation Gold Recovery

FIG 1 Overview of Porgera flotation circuit



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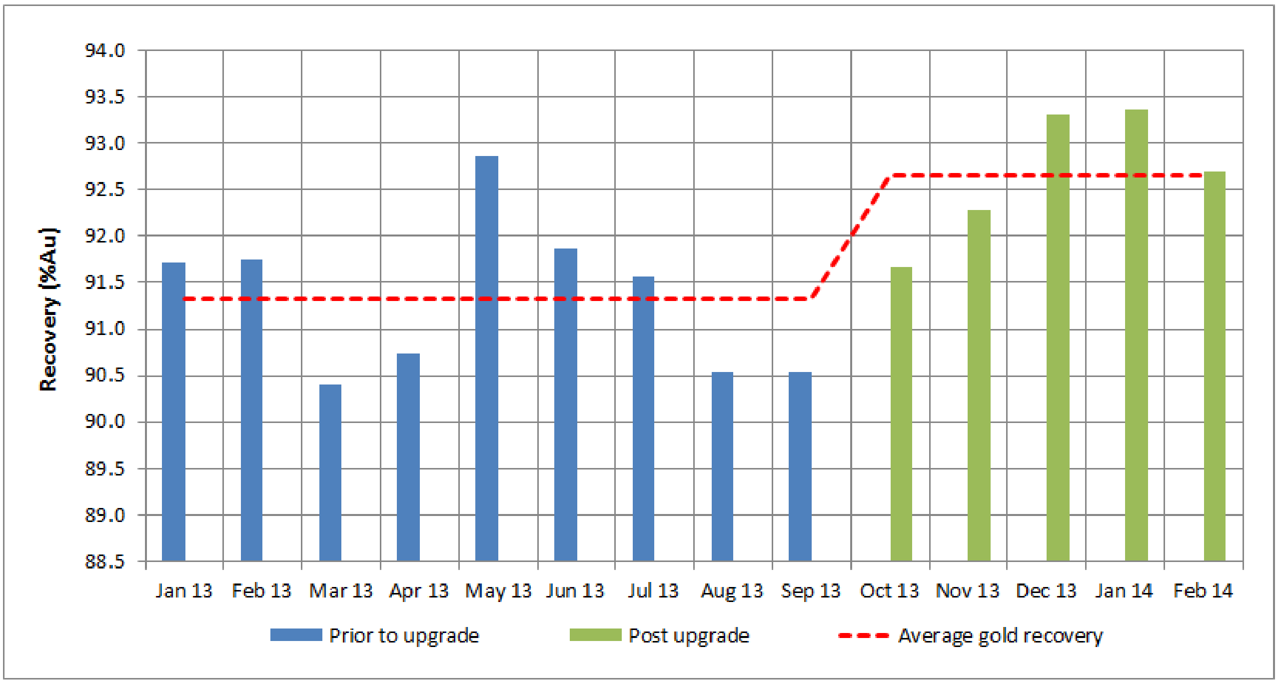
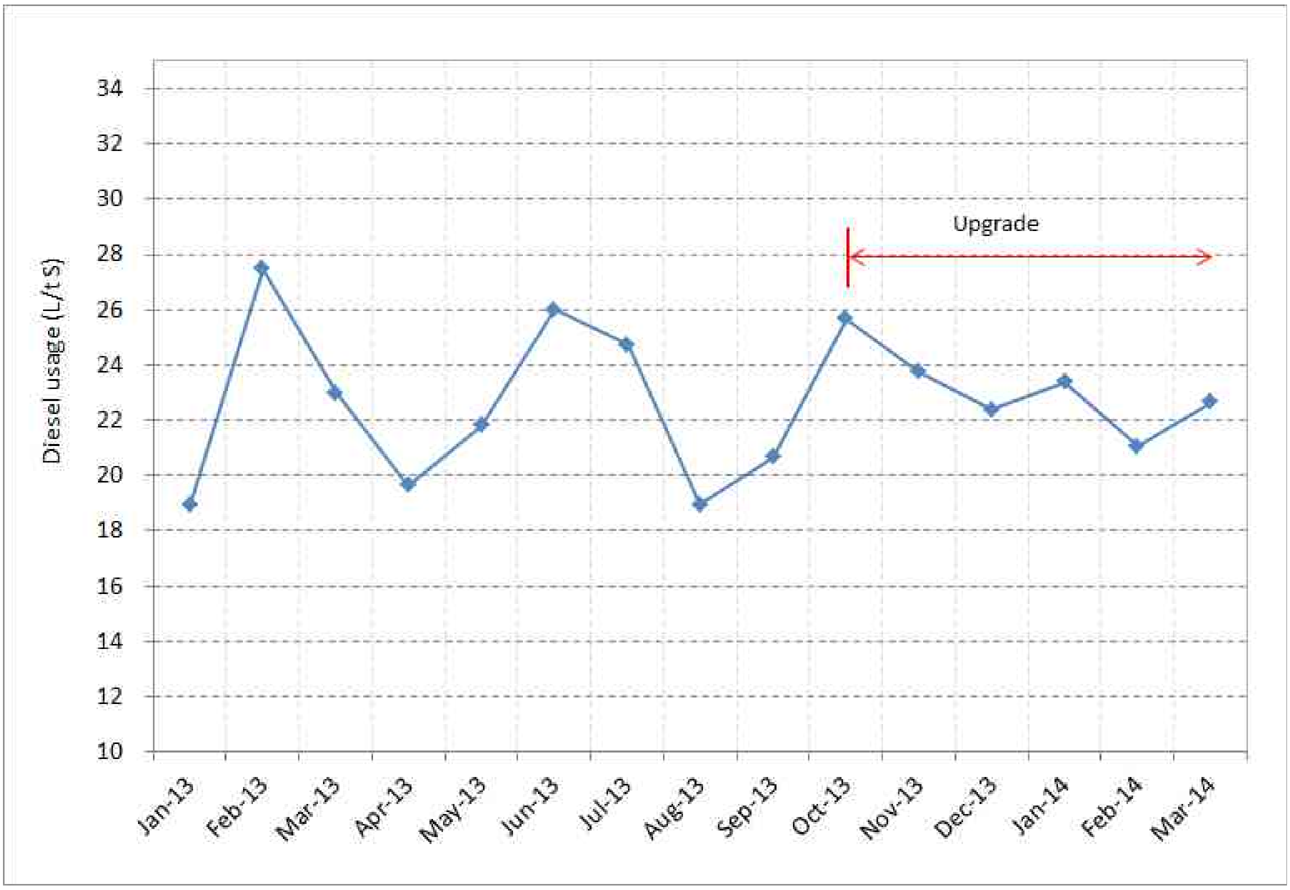


FIG 11 Diesel usage in the pressure oxidation circuit, pre- and post-upgrade.


Upgrade
Diesel usage (L/t S)
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Feb-13
Mar-13
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Jun-13
Jul-13
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Oct-13
Nov-13
Dec-13
Jan-14
Feb-14
Mar-14

TABLE 1 Difference between Blue Cube and Laboratory data (Kewe, 2014)

	Assay Lab	Blue Cube	Difference
Total Sulphur (%)	14.3	15.5	**-1.3**
Count	501	501	**0.0**
Minimum	7	10	**-2.9**
Maximum	23	25	**-2.2**
STD Deviation	1.8	1.4	**0.4**

TABLE 2 Normalised Flotation Circuit Gold Recovery Increase (Kewe, 2014)

Gold Feed Grade (g/t Au)	0.08
Lithology (%)	0.12
Size (%)	0.00
Residence Time (mins)	0.21
Recovery (%)	1.58