

NECESSITY DRIVING CHANGE AND IMPROVEMENT TO THE CLEANER CIRCUIT AT LUMWANA COPPER CONCENTRATOR

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ABSTRACT

Lumwana is an open pit Copper mine located in the Northwestern Province of Zambia approximately 80 km west from the provincial capital of Solwezi, approximately 300 km northwest from the Copperbelt and 700 km northwest from the national capital of Lusaka. The mine has two major Copper deposits: Malundwe and Chimiwungo. Copper mineralization includes Chalcopyrite, Bornite and Chalcocite. In addition to Copper, these deposits also contain the undesirable element Uranium contained in vein hosted and disseminated Uranite. The processing plant was designed using conventional technologies: semi-autogenous grinding (SAG) and ball mill for grinding, and mechanical cells for rougher and cleaner flotation. Soon after commissioning in early 2009, it was recognised that two stages of conventional cleaning were unable to produce plant final Copper concentrates with the desired Uranium grades. Studies have shown that a significant quantity of liberated and fine Uranium particles (up to 80-90%) is recovered with the concentrate by entrainment. Lumwana Operations sought the use of the Jameson Cell technology after observing successful implementation at other sites in rectifying similar issues. In late 2009, Jameson Cell pilot-plant test work was conducted at the site and this quickly led to the installation of a full-scale B5400/18 model into the existing cleaner circuit. Inclusion of the Jameson Cell resulted in the plant being able to effectively produce clean and saleable concentrate with Uranium contents consistently below acceptable levels. Initially designed to be used as a cleaner scalper cell at the head of the existing conventional cell circuit, subsequent operational issues with the existing recleaner cells forced reconfiguration of the cleaner circuit and reintroduced the Jameson Cell for the recleaning duty. This paper reports the Lumwana Operation from the first two years of operation where it struggled to produce a saleable concentrate with Uranium grades below 150 ppm, which is the maximum allowable limit set out in the smelting contracts, to steps taken in the subsequent years to implement a satisfactory solution. The plant can now consistently produce a clean Copper concentrate with Uranium grades well below 130 ppm and the overall improvements implemented at site have seen the overall plant recovery improve by 1.3%.

KEYWORDS

Flotation, Jameson Cell, Uranium, Copper, Cleaner Circuits, Zambia.

INTRODUCTION

Lumwana is an open pit Copper mine located in the Northwestern Province of Zambia approximately 80 km west from the provincial capital of Solwezi, approximately 300 km northwest from the Copperbelt and 700 km northwest from the national capital of Lusaka (Figure 1). The Lumwana Project was developed by the former Canadian mining company Equinox Minerals Limited (“Equinox”), through its Zambian subsidiary Lumwana Mining Company Limited. The mine was commissioned in 2008 and commercial Copper production started in the second quarter of 2009. In June 2011, Barrick Gold Corporation (“Barrick”) acquired Equinox whose primary asset was the Lumwana Mine.



Figure 1 – Map of Africa and Zambia showing location of the Lumwana operation

The Lumwana mine contains two major Copper deposits: Malundwe and Chimiwungo, that are hosted almost entirely within Muscovite-phlogopite-quartz-kyanite schists with disseminated sulphides dominated by Chalcopyrite and Bornite (Davis et al., 2006). Malundwe, the smaller deposit, was mined first and has high Copper grades along with Gold, Uranium and sporadic high Cobalt grades. The Chimiwungo deposit is much larger in size but with lower Copper grades, high Cobalt grade zones and Uranium mineralization (Davis et al., 2006). Mining of the Chimiwungo deposit commenced in August 2012. The expected life of mine is 20 years for mining and 33 years for processing.

The processing plant (Figure 2) was designed to treat 2,500 tonnes per hour (tph) of ore with head grades between 0.4 to 0.6% Cu using a SAG mill (38'x18', 18 MW) and ball mill (26'x40', 16 MW) to produce a primary grind with D_{80} of 300 μm for subsequent flotation. The flotation circuit consists of two parallel lines of seven 160 m^3 Wemco cells for rougher flotation followed by two stages of conventional cleaning using four 50 m^3 Dorr-Oliver cells for the first stage of cleaning, three 50 m^3 Dorr-Oliver as cleaner scavengers and five 17 m^3 Dorr-Oliver for recleaning. A second ball mill (13'x23', 1.25 MW) is used to regrind the rougher (and cleaner scavenger) concentrate to a D_{80} of 106 μm for cleaning. The plant, commissioned in early 2009, is now treating a higher tonnage (3,200 t/h) than the nameplate design. The Copper concentrate produced from the plant (typically

between 35 to 45% Cu depending on Copper mineralogy) is sold to different smelters where the maximum allowable Uranium limit in the contracts is 150 ppm.

This paper chronicles the Lumwana Operation from the first two years of operation where it struggled to produce a saleable concentrate within the acceptable Uranium limits to steps taken in the subsequent years to implement a solution.

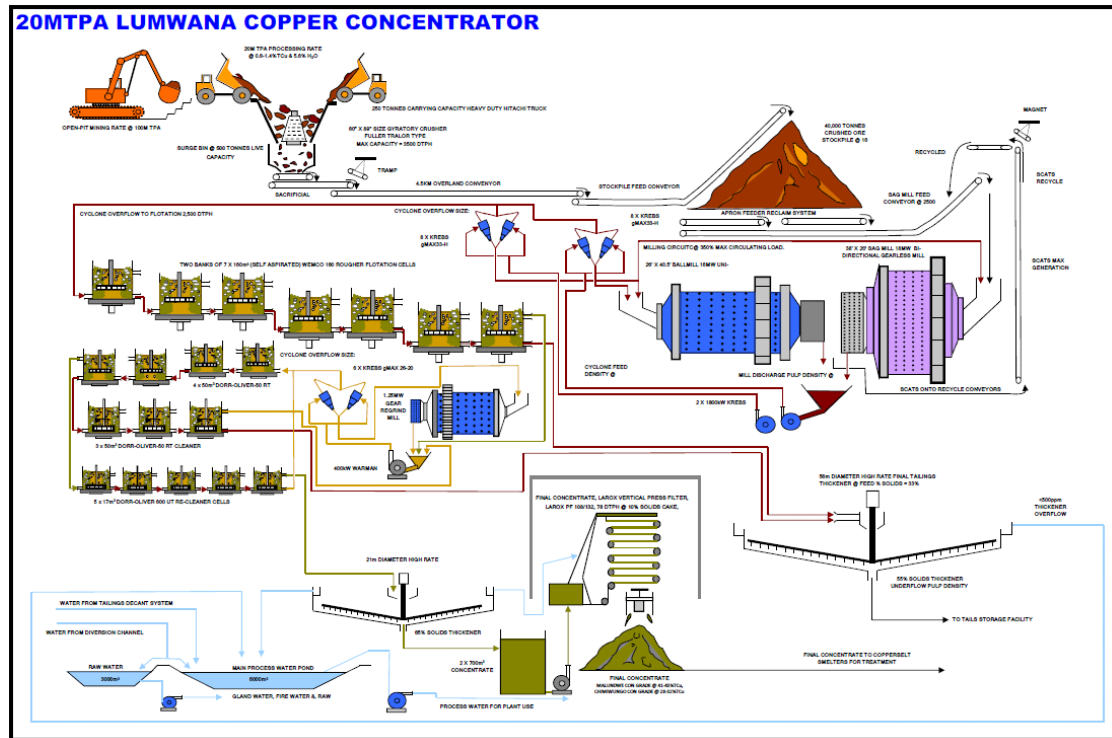


Figure 2 – Flowsheet of the original design of the ore processing plant at Lumwana

PROBLEM DEFINITION

Several months into normal operation and following the commissioning of the concentrator it was recognised that two-stages of conventional cleaning were unable to consistently produce final plant Copper concentrates within the acceptable Uranium limits. Figure 3 shows the Uranium grade of the plant final Copper concentrate and of the feed over the first two full years of operation from 2009 to 2011. Firstly, it shows that the level of Uranium in ore treated is extremely variable and can be below 10 ppm, but can also be as high as 400 ppm. Similarly, the Uranium grades in the final concentrate are just as variable and in many instances exceed the highest acceptable limit of 150 ppm. ‘Off spec’ concentrate need to be stockpiled and blended with the cleaner concentrates with lower levels of Uranium. Figure 3(B) shows the Uranium grades in the final Copper concentrate is fairly evenly spread across a wide range of values which highlights the poor ability of the plant to consistently produce a clean concentrate and to effectively deal with the feed variations. Post July 2010, the Uranium grades in the feed appeared lower than the first year of operation but strangely, the Uranium grade of the final Copper concentrate does not follow this trend and remained on the same level which emphasises the inefficiency of the cleaning circuit to reject Uranium.

Uranium contained in the Lumwana deposit is mostly present as Uranite having particle sizes as fine as 10 μm and is associated with the same lithology that hosts the Copper mineralization (Smith, 2013). Mineralogical analysis and diagnostic tests on plant cleaner samples (from bench scale flotation tests) have showed that the majority of the Uranium particles are very fine, liberated and are admitted into the froth by entrainment. So in theory, much of the Uranium can potentially be rejected, but the problem was that the conventional cleaner cells in the plant were ineffective in controlling

entrainment, exacerbated by the changing amounts of Uranium in the ore. In fact, plant data (Figure 4) showed that the recleaner stage is totally inadequate as it did not appear to upgrade Copper, nor reject any Uranium as evidenced by the fact that the Copper and Uranium grades in the first cleaner concentrate and the recleaner (final plant) concentrate were similar in value.

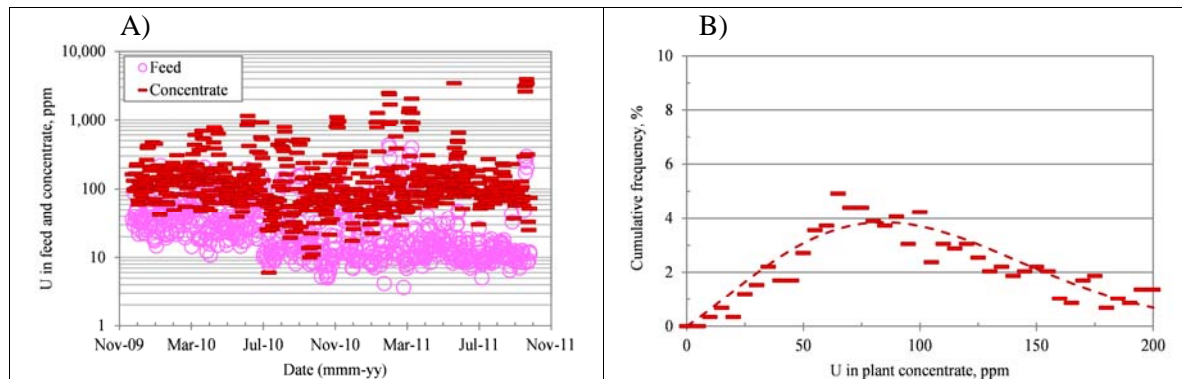


Figure 3 – Uranium grade in the flotation feed and final Copper concentrate produced by the plant over the first two years of operation

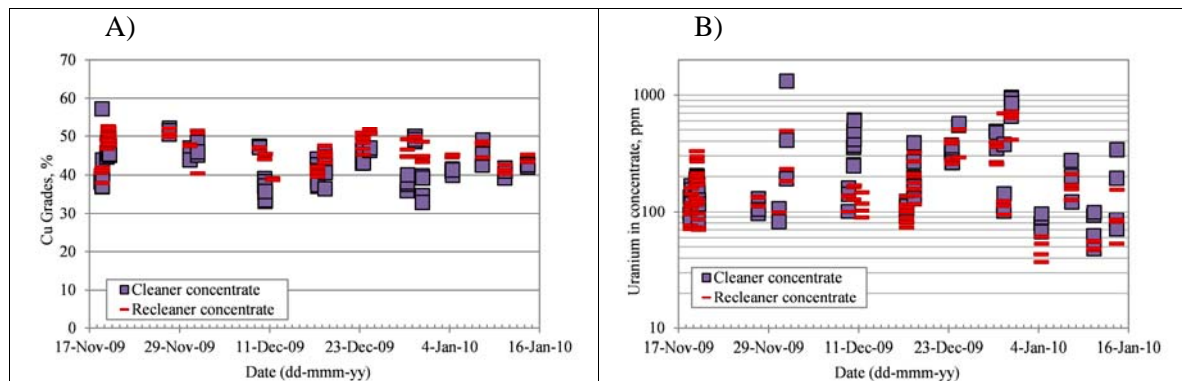


Figure 4 – Grade of Uranium in the plant cleaner and recleaner concentrate shown consecutive months of operation. (A) Copper grade, (B) Uranium grade

Lumwana sought the use of the Jameson Cell technology to address its Uranium issue after seeing the successful implementation at OZ Mineral's Prominent Hill operation which produces high grade and clean concentrate by rejecting the penalty element, Fluorine (Barns et al., 2009). Since then, the Jameson Cell technology has been retrofitted to a number of Copper concentrators to solve process challenges in existing conventional cleaner circuits (Araya et al., 2013). These include PanAust's Phu Kham operation in Laos as described by Bennett et al. (2012) and Newcrest's Telfer operation in Western Australia as described by Seaman et al. (2012). Other reasons for the success of the Jameson Cell technology in these applications reflect its high productivity in a small footprint and simple integration into an existing plant resulting in highly desirable minimal disruption to production

THE JAMESON CELL

The Jameson Cell is a robust, efficient and innovative flotation technology driven by fluid mechanics. Commercialised in the late 1980s, it has been continuously developed over two decades and now has more than 320 installations worldwide across many industries including coal, base metals, industrial minerals, potash and oil sands.

In a Jameson Cell feed slurry is first pumped through a restriction (the slurry lens orifice) to create a high pressure jet which then enters a cylindrical device called a downcomer (Figure 5). The jet of liquid first shears and then entrains air from the atmosphere. Removal of air into the jet causes a vacuum to be generated inside the downcomer. When a hydraulic seal is formed at the bottom of the downcomer, the vacuum causes a column of slurry to be drawn up inside the downcomer. The jet of slurry plunges onto the liquid surface and the high kinetic energy of the jet then disseminate the entrained air into very fine bubbles (Evans et al., 1995). In this zone, the high intensity of the system creates a very favourable environment for the bubbles and particles to collide and attach. The air bubbles and mineral particles move continuously down the downcomer before exiting into the tank. The particle laden bubbles then float to the top to form the froth whilst the hydrophilic particles remain in the pulp phase to be removed as tailings. To ensure consistent operation, tailings recycle is employed. This dampens feed fluctuations to the cell allowing the downcomer to operate at a constant feed pressure and flowrate (Cowburn et al., 2005). The high rate of mixing from the high pressure slurry jet and the fact that the air is self-aspirated, allows the Jameson Cell to have no moving parts other than the feed pump. No agitators or compressors are required.

Due to rapid kinetics and a separate contact zone in the downcomer, the tank is not sized for residence time, so tank volumes tend to be very much smaller than equivalent capacity mechanical and column cells (Harbort et al., 2003).

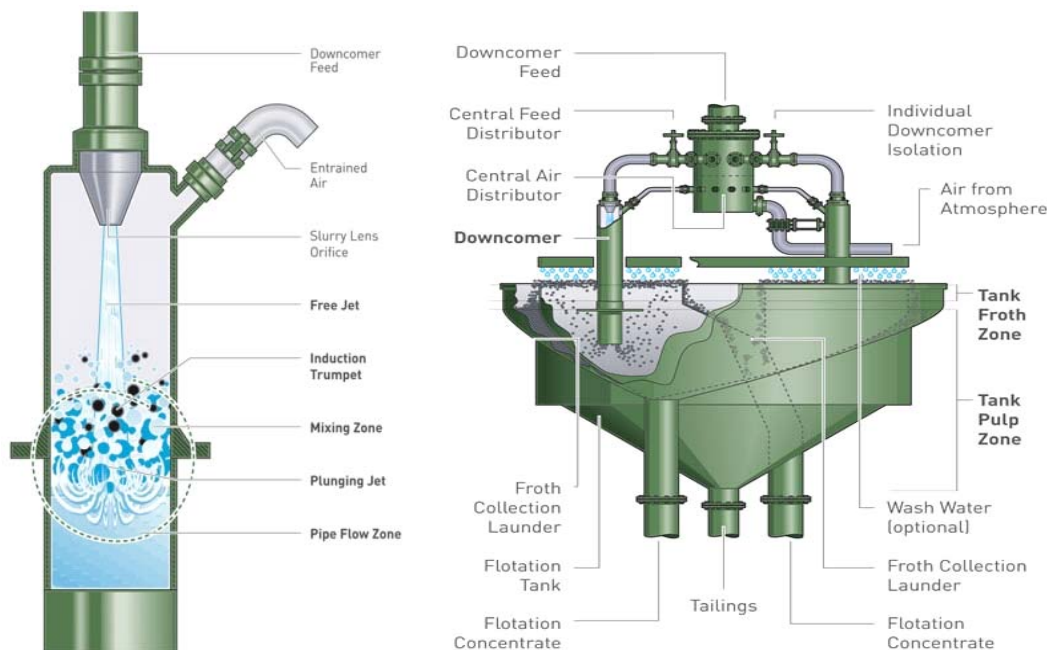


Figure 5 – The Jameson Cell showing downcomer (on left) and overall assembly in tank (on right)

JAMESON CELL PILOT PLANT TESTWORK

In late 2009, a Jameson Cell L500 pilot plant test rig was brought onto the site to allow continuous test work to be conducted. This pilot plant (Figure 6) is a self-contained unit which has a

100 mm diameter downcomer in a 500 mm diameter flotation tank, a washwater system, a pump box incorporating the tailings recycle mechanism and a feed pump. The feed to the cell is a bleed stream from the plant that can be varied from 3 to 8 m³/h of slurry to provide the desired quantity of tailings recycle (30 to 80%) for testing. The control panel of the pilot unit has pressure gauges to measure feed and vacuum, rotameters for controlling air and wash water flow rates and automatic control of cell level and hence, control of the froth depth.



Figure 6 – Jameson Cell L500 pilot plant test rig at Lumwana site

The pilot-scale rig was operated in continuous mode to simulate Jameson Cell performance in a full scale and the test campaign was carried out over a two-month period from November 2009 to January 2010. Different streams within the cleaner circuit were investigated but the focus was on treating the cleaner feed stream as it was envisaged that the Jameson Cell would be installed in a cleaner scalper duty in the full-scale plant. The results in Figure 7 show that, firstly, the Jameson Cell can produce the required final grade Copper concentrate (typically between 35 to 45% Cu depending on mineralogy) in a single stage of flotation. Copper recovery ranged from 40 to 90% which was controlled by the process variables and settings used in each test. The Copper grade/recovery curve is flat across the entire recovery range indicating that the Copper minerals recovered must be well liberated. The selectivity achieved between Cu and U recovery is rather impressive. It shows that 80-90% of the Uranium in the cleaner feed stream can be rejected. The selectivity remains good even up to a Copper recovery of around 80-90%, remembering again that this is achieved in a single stage of flotation.

A)	B)
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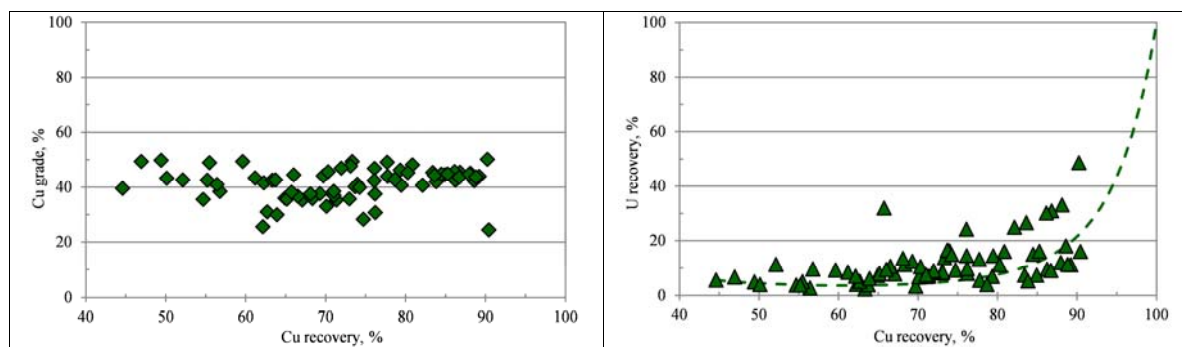


Figure 7 – (A) Copper grade/recovery curve and (B) Copper/Uranium selectivity achieved by the Jameson Cell pilot plant treating the cleaner feed stream

Figure 8 compares the Uranium grades of the Copper concentrate produced by the Jameson Cell in a single stage of flotation versus two stages of conventional cleaning in the plant when treating the same feed. The Copper grades in the concentrate are similar in both cases (not shown) but clearly, the Jameson Cell is far superior in rejecting entrained particles of Uranite. Figure 8 also highlights the fluctuating nature of Uranium grade in the cleaner feed stream which perhaps, explains the challenge for the plant to be able to consistently produce ‘in spec’ concentrates. However, the Jameson Cell can consistently produce a Copper concentrate with Uranium levels well below 130 ppm by effectively removing the entrained fine and liberated Uranite particles. Tests showing Copper concentrates with the higher Uranium grades, say above 100 ppm, in Figure 8 can be attributed to the remaining Uranium that is locked within Copper mineral particles. Otherwise, Uranium grades in the Copper concentrates are typically much lower (20-80 ppm).

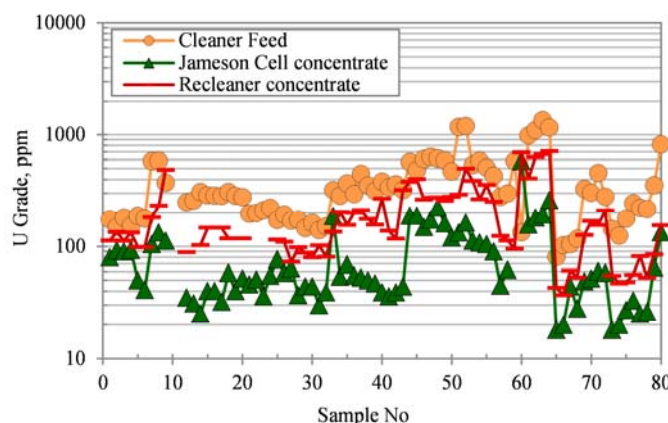


Figure 8 – Uranium grade comparison for single stage Jameson Cell pilot plant versus two stage of conventional cell cleaning in the plant

FULL SCALE JAMESON CELL INSTALLATION

The positive outcome of the pilot plant test work convinced Lumwana to purchase a full scale Jameson Cell in May 2010. The location of the installed Jameson Cell is shown in Figure 9. A model B5400/18 Jameson Cell (which is a 5.4 diameter circular cell with 18 downcomers) was appropriate to treat the tonnage and volumetric flowrate of the cleaner feed stream and this cell was to be installed at the head of the existing cleaner circuit (Figure 10). Lumwana chose an external engineering company for drafting and designing the structure and layout but the project was managed in-house by Lumwana site. The Jameson Cell was installed in a stand-alone structure next to the existing cleaner circuit with the cell elevated to allow the concentrate produced from the Jameson Cell to gravity flow to the existing final concentrate hopper and the tailings from the Jameson Cell to gravity flow into the distribution box at the head of the plant cleaner circuit. The higher cost of elevating the cell was offset by the lower operating and maintenance costs compared to pumping concentrate and tailings.

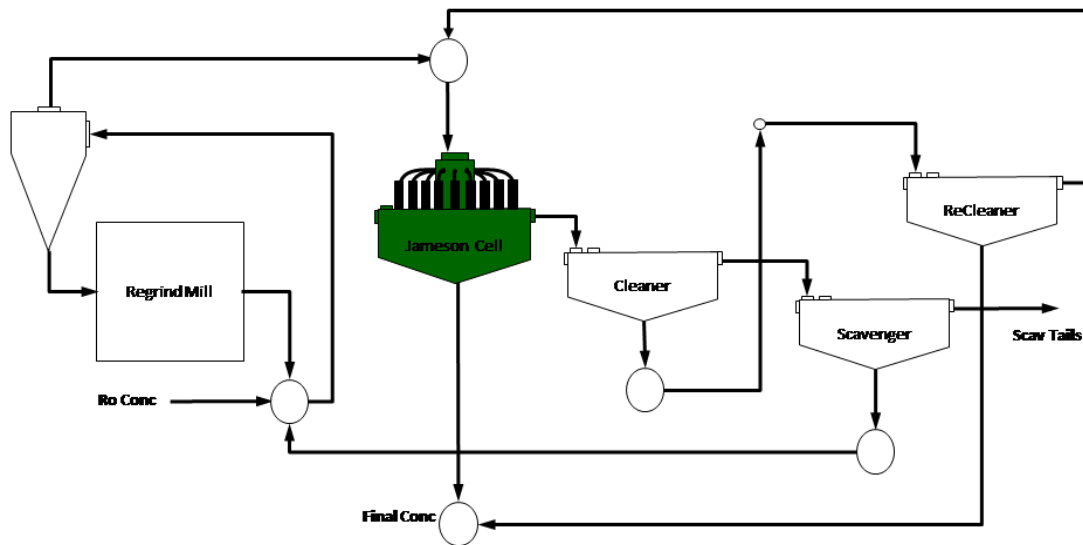


Figure 9 – Flowsheet showing the inclusion of a Jameson Cell in a cleaner scalper duty at the head of the existing circuit

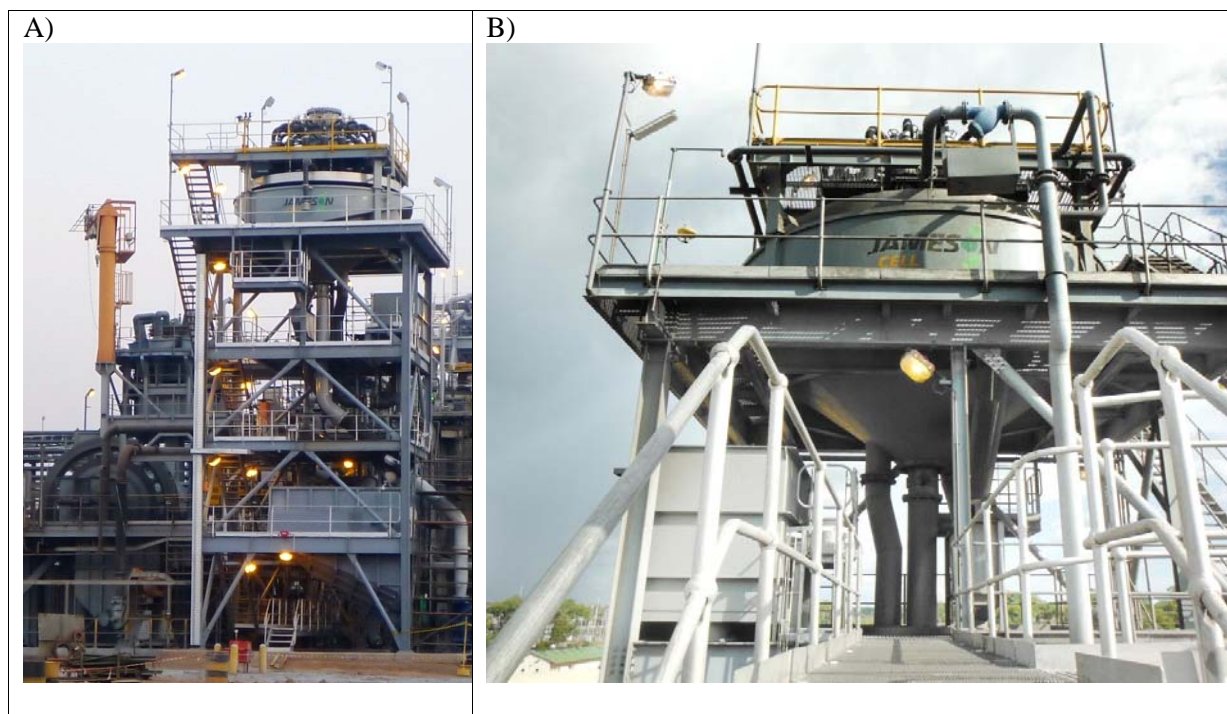


Figure 10 - The full scale model B5400/18 Jameson Cell installed at Lumwana

Due to some minor problems on the project caused by third party contractors (relating to logistics and local fabrication of parts), the installation of the cell was several months late and commissioning of the Jameson Cell commenced in July 2011. This process is straightforward and usually takes less than a week to complete but in this case, other issues arose which slowed progress. On start-up, the feed pump delivered too high a feed pressure (200 to 220 kPa) and excessive volumetric flow rate to the Jameson Cell. The pulley on the motor needed to be changed to reduce the feed pressure back to the correct design value (150-160 kPa). The polyethylene pipes connecting the Jameson Cell tails outlet to the External Recycle Mechanism (ERM) box, which controls tailings recycle, was of the wrong schedule, i.e., too small an internal diameter, which restricted the flow of

tailings from the Jameson Cell. The whole assembly had to be dismantled and pipe sections needed re-working (ground out) to increase the diameter. Due to a design error by the engineering company contracted to design the circuit, the concentrate pipes from the Jameson Cell tank outlets to the final concentrate hopper were erroneously reduced to 150 mm when they should be 400 mm. This caused the concentrate (which is frothy) produced by the Jameson Cell to back up into the launders. These pipes were removed and replaced with the larger ones (400 mm). All these issues were quickly resolved but the modifications required several months to rectify so the commissioning process took much longer than expected and the Jameson Cell was not fully operational until August 2011.

On handover, the metallurgical performance of the full-scale Jameson Cell was fully assessed by the operations personnel to see if it matched the performance demonstrated from the pilot plant test work as assured by Xstrata Technology. Figure 11 compares the performance of the full scale Jameson Cell to that of the pilot plant. Results are almost identical in terms of the Copper recovery that can be achieved and more importantly, the excellent selectivity between Copper and Uranium.

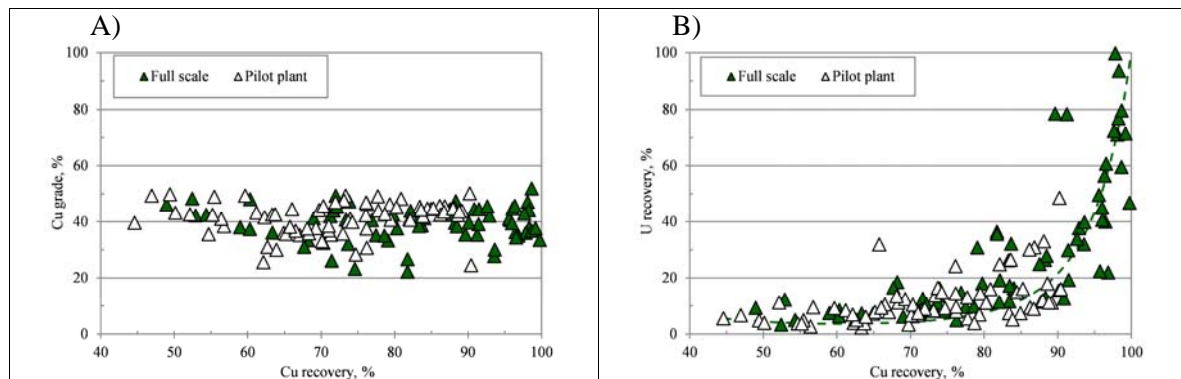


Figure 11 – Comparison of metallurgical performance of the full scale Jameson Cell to the pilot plant. (A) Copper grade/recovery, (B) Copper/Uranium selectivity

The high Copper recovery that the Jameson Cell is able to achieve while still being able to reject Uranium (up to 80-90%) at the head of the cleaner circuit should significantly lessen the load in the cleaner circuit downstream. Although the cleaner circuit is now treating a stream with higher levels of U (tails from the Jameson Cell), it needs to recover much less Copper, and consequently it can be pulled much more slowly, i.e. by increasing the froth depth and using less air, thereby allowing the froth to drain more thoroughly which will decrease entrainment. The lower solids content of the slurry feeding the conventional cleaner circuit will also be beneficial in reducing entrainment by dilution cleaning. Figure 12 illustrates the Uranium grades in the Copper concentrate produced by the Jameson Cell and the recleaner conventional cells over a two month period in 2011. These two concentrates are combined to give the overall plant final concentrate which is also shown in the graph. The figure on the right shows the whole data set: sorted based on frequency of occurrence, organized in bins with sequential increments of 5 ppm and presented as cumulative distribution which is a powerful tool to compare concentrates of different quality. A perfect flotation system would generate a vertical line, meaning that 100% of the time the same U grade is achieved. Deviation from the vertical line indicates less than perfect performance, which is more realistic, and the spread of the probability distribution. In this case, it is highlighted the superior performance of the Jameson Cell compared to the recleaner cell. The Jameson Cell curve has a much steeper slope meaning it can produce Copper concentrates within a narrow range of Uranium grades. It can produce Copper concentrates with Uranium grades below 100 ppm for about 90% of the time. In comparison, the curve for the recleaner cell is very broad. The concentrate produced by the recleaner mechanical cells is very high in Uranium and when combined with the clean low Uranium grade concentrate from the Jameson Cell to give the final plant concentrate, the overall benefit provided by having a Jameson Cell in the circuit is diminished.

A)	B)
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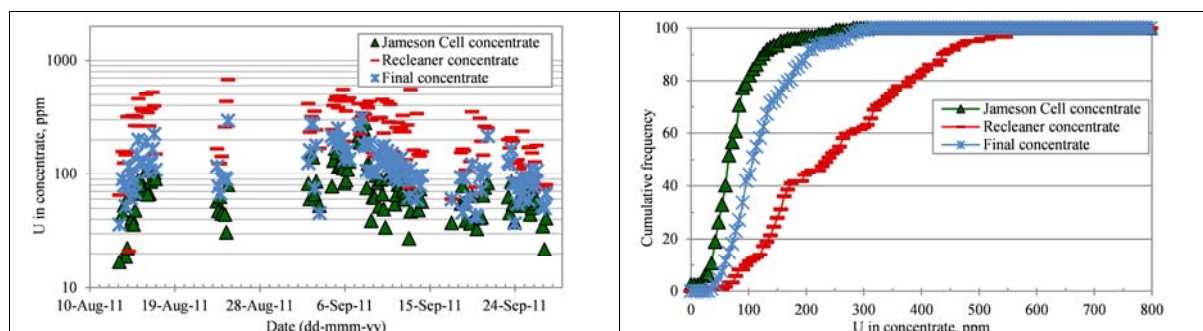


Figure 12 – U grade of the Copper concentrate produced by the full scale Jameson Cell, the recleaner cells and the combined plant final concentrate

(Note: The same data is presented as date [A] and cumulative frequency of occurrence [B])

The poor performance of the recleaner cells was identified as an operational issue long before the Jameson Cell was installed. Essentially, the dart valves on this bank of cells do not function properly so the froth depth and hence, pulling rate of these cells cannot be controlled. This in part explains the lack of ability of these cells to reject Uranite, as shown in Figure 4 (for the original plant) and Figure 12 (after the Jameson Cell was installed). Lumwana Operations management was initially keen to remove this bank of recleaner cells from the circuit and as the installation of the Jameson Cell was primarily intended to produce clean concentrate rather than to add more capacity, the logical move was to re-allocate the duty of the Jameson Cell to recleaning (see Figure 13).

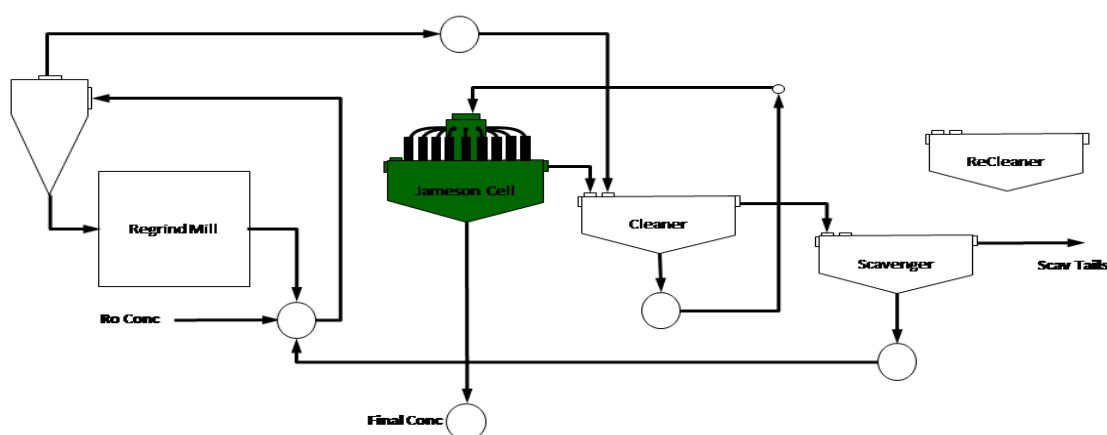


Figure 13 – Revised cleaner circuit flowsheet showing the Jameson Cell operating in the recleaner duty. (Note: the original plant recleaner cells are taken offline)

An initial concern was whether this cleaner circuit configuration would affect the overall plant recovery as the Jameson Cell was not originally intended to make the entire plant final concentrate. With pipework in place to be able to change back the Jameson Cell to the cleaner scalper duty if required, trials on this new circuit were commenced in early 2012. With the Jameson Cell now treating the cleaner concentrate, it was shown to be able to consistently produce a very clean concentrate, low in Uranium. Several weeks of continuous operation resulted in no detrimental effect on the overall plant recovery indicating there was sufficient capacity in the installed Jameson Cell to produce the entire plant concentrate. The plant team then decided to continue using the Jameson Cell permanently in the recleaner duty.

Figure 14(A) shows the Uranium grades in the plant Copper concentrate from plant daily samples collected in the first two years of normal operation (November 2009 to 2011), followed by the period from then up to August 2013 when the Jameson Cell replaced the conventional recleaner bank. There is clear reduction in the Uranium grade in the Copper concentrate after the Jameson Cell was installed. Figure 14(B) shows the frequency distribution, i.e. a function that shows the number of

observations within a defined interval, of the Uranium grades in the Copper concentrate for the two separate periods (the frequency distribution after the Jameson Cell was installed is overlaid to the graph shown in Figure 3(B)). The difference is impressive and shows a significant shift in the curve to the left where the average Uranium grade in the Copper concentrate produced is now much lower (65 ppm compared to 85 ppm before the Jameson Cell was installed) and the narrowing of the distribution and higher relative frequency around the average which means the plant is able to produce a lower Uranium grade Copper concentrate more of the time. Also, the ‘tail’ on the right is reduced to zero around 130 ppm which means the plant is always producing final grade Copper concentrate with Uranium grades below this level. This is a vast improvement compared to the original two-stage conventional cleaner circuit where the Uranium grades in the final Copper concentrate appeared to be highly indiscriminate (as evidenced by the wide deviation around the average as shown in Figure 14(B)) and as random as the Uranium grades in the feed treated.

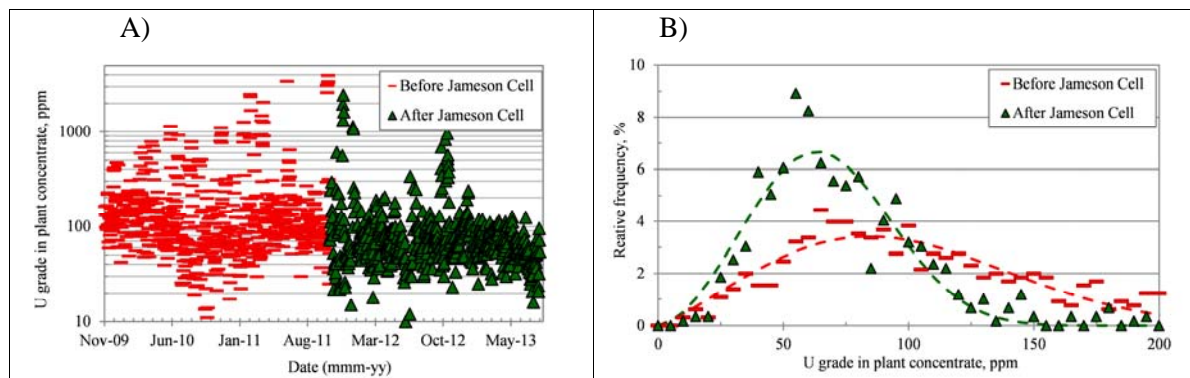


Figure 14 – Comparison of the Uranium grades in the plant final Copper concentrate for the periods before and after installation of the Jameson Cell

Figure 15 shows the frequency distribution for Copper recovery in the plant for the periods prior to and after the Jameson Cell was installed. It can be seen that statistically, the two periods form two independent populations. The period after the Jameson Cell shows the average Copper recovery has increased by 1.3%, which is significant. However, this improvement cannot be solely attributed to replacing the conventional recleaner cell bank with a single Jameson Cell. The two years following the introduction of the Jameson Cell has seen Lumwana Operations implement a number of process improvement strategies including ways to achieve more consistent feed through the plant and reagent-focused initiatives including trials and optimisation.

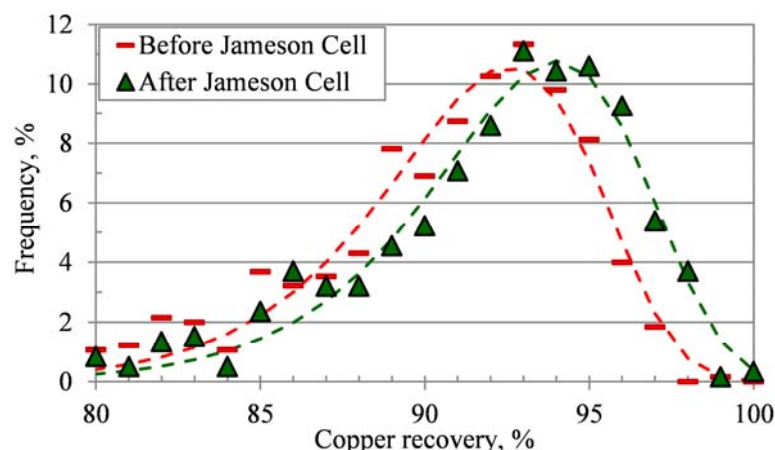


Figure 15 – Comparison of the overall plant Copper recovery for the periods before and after installation of the Jameson Cell

CONCLUDING REMARKS

In the first two years of operation, the Lumwana concentrator struggled to consistently produce a saleable Copper concentrate with acceptable levels of Uranium below 150 ppm. The initially installed two-stage conventional cleaner circuit was unable to handle the varying nature of Uranium content in the ore treated and proved ineffective in rejecting fine Uranite particles. An urgent solution was sought which commenced with Jameson Cell pilot plant testing at the plant site. The results obtained confirmed that the majority of the Uranium (around 80-90%) enters into the froth by entrainment and could be rejected to produce a high grade Copper concentrate with Uranium grades well below the desired limits.

A full-scale Jameson Cell was purchased and installed in a cleaner scalper duty at the head of the existing cleaner circuit. The Jameson Cell produced a very clean Copper concentrate consistently low in Uranium and the performance of the full scale cell was identical to that shown during piloting. However the poor performance of the recleaner conventional cells which produces a 'dirty' concentrate very high in Uranium diminished the overall benefit provided by the Jameson Cell and as a consequence the circuit was altered. The recleaner bank was taken offline and the duty of the Jameson Cell was changed to recleaning. This rearrangement has allowed the plant to consistently produce a clean saleable final grade cleaner concentrate with Uranium grades averaging 65 ppm and always below 130 ppm. While the Jameson Cell was specifically employed to solve a concentrate grade issue at Lumwana rather than adding cleaning capacity, its installation and other initiatives undertaken by site personnel over the past two years has seen recovery at the plant increase by 1.3%.

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