Improving performance at Rustenburg Base Metals Refiners copper tankhouse: Operational review and embracing fundamentals

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Abstract

The copper tankhouse at Rustenburg Base Metals Refinery is an essential component of the Anglo American Platinum value chain. The tankhouse uses starter-sheet technology that was adopted in the 1980s, so dependence on manually intensive labour and overall operational excellence has a significant impact on process performance. An efficient, stable, and sustainable electrowinning process contributes to minimising energy consumption and reducing operational costs, and enables improved product quality and increased throughput. Historic performance of this tankhouse has often been suboptimum over prolonged periods. An in-depth operational review of performance from 2018–2024 was carried out to understand challenges, risks, and high-impact factors that contribute to poor performance. Implementation of adherence to fundamental operational basics identified from global best practice, such as the frequency and quality of cell cleaning and maintenance, preventing backlogged harvesting or maintenance, preserving cell-top furniture conditions and integrity of electrodes, preventing short circuits and poor current distribution, and maintaining a high level of operational discipline, has since contributed to an era of exceptional performance. Root-cause analysis fault trees pertaining to poor current efficiency and high scrap rate are summarised. Current efficiency has significantly improved since 2021, now consistently exceeding 88%. The copper scrap rate, previously believed to be limited to a minimum of 4%, achieved a historic monthly low record of 2.06% in 2023. Chemical and physical quality has considerably improved, and cathodes exhibit minimal morphological defects.

Keywords

Rustenburg Base Metal Refiners, copper, electrowinning, starter-sheet operation, current efficiency, scrap rate

Introduction

The Anglo American Platinum (AAP) Rustenburg Base Metals Refinery (RBMR) forms a crucial and enabling part of the platinum value chain in the hydrometallurgical processing of platinum-group metals (PGM) and base metals (BM) to final marketable product form. The RBMR process and developments since its inception in 1981 are well documented by Hofirek and Halton (1990), Hofirek and Kerfoot (1992), Hofirek and Nofal (1995), and Bryson et al. (2008). The main feedstock to RBMR, which comprises the magnetic concentrator plant (MCP) and base metal refinery (BMR), is Waterval converter matte (WCM) derived from the upstream pyrometallurgical converter process that is based on Ausmelt technology. To achieve the required PGM upgrades and BM recovery from the mined ore, AAP uniquely makes use of a slow-cooling process followed by magnetic separation, as opposed to whole matte leaching (Hoosen et al., 2018). The crushed WCM entering the MCP undergoes several milling, magnetic separation, and leaching stages to recover high-grade material that forms the feedstock (final concentrate; FICO) to the precious metals refinery (PMR). The non-magnetic portion, also referred to as nickel copper matte (NCM), together with the magnetic concentrate leach solution (pressure vessel liquor; PVL), is processed at the BMR to produce final nickel, copper, cobalt sulfate, and sodium sulfate products. NCM typically comprises ~ 42% Ni, ~ 28% Cu, ~ 2% Fe, and ~ 23% S, with copper being the second most abundant element (Bryson et al., 2008).

A simplified illustration of the input, outputs, and processing plants of RBMR is presented in Figure 1. The BMR comprises typical hydrometallurgical processes pertaining to leaching (atmospheric, oxidative, and non-oxidative), solution purification (precipitation, solvent extraction, and ion exchange), and metal recovery (electrowinning (EW), precipitation, crystallisation).

Since commissioning of the original flowsheet, key refining capacity expansions have taken place to increase throughput, improve efficiency, and create a safer processing environment for the operation. By

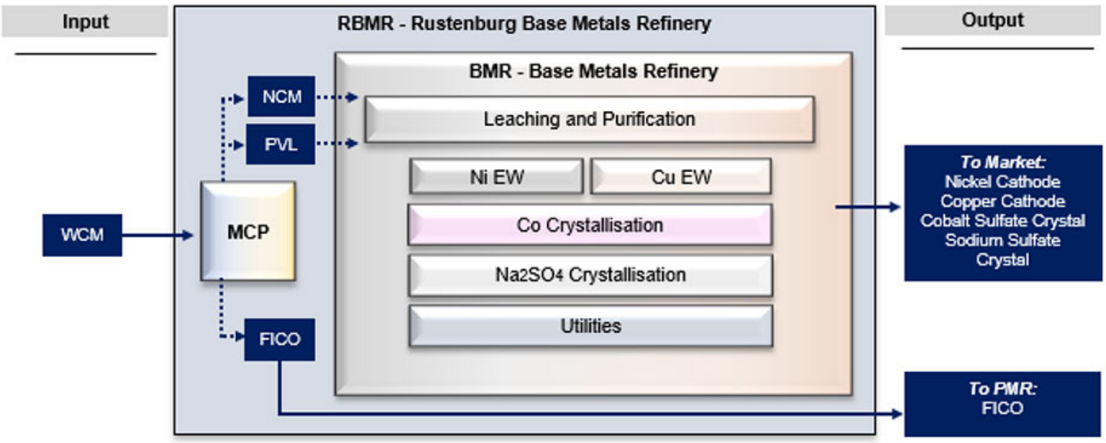

Figure 1—Simplified diagram illustrating input, outputs, and processing plants within Rustenburg Base Metals Refinery

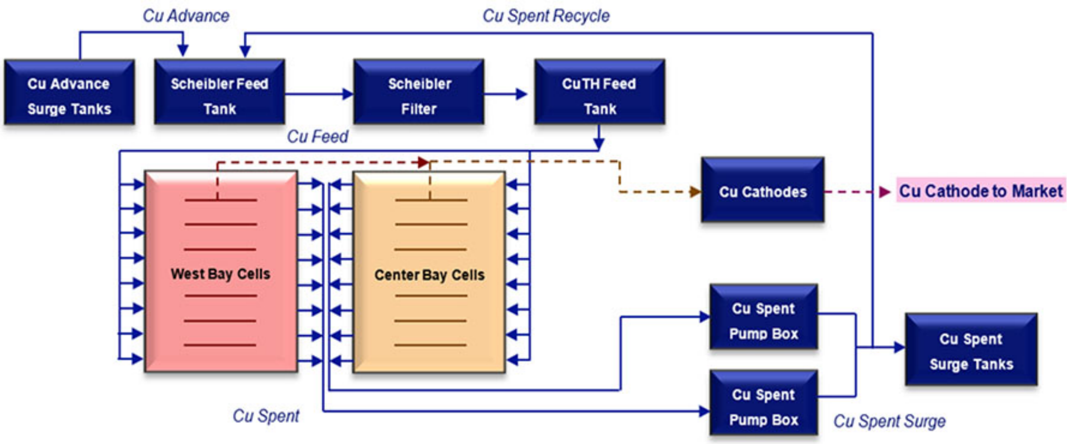

Figure 2—High-level process flow diagram of the Rustenburg Base Metals Refinery copper tankhouse

2024, the RBMR had undergone two significant expansion projects in its 43-year existence. In 1993, AAP expanded the operation to produce 21 kt/a nickel cathode from the original design of 19 kt/a. The initial design of 12 kt/a copper cathode remained unchanged. In 2011, an increase in platinum processing throughput necessitated an associated increase in key BM outputs and consequent expansion of BMR. This resulted in significant changes to the leaching and purification stages of the refinery, together with construction of a state-of-the-art modernised nickel EW tankhouse, which increased nickel production capacity to 32.4 kt/a from 21 kt/a and copper production to 20.6 kt/a from 12 kt/a.

Copper electrowinning at Rustenburg Base Metals Refiners

The RBMR copper tankhouse is currently one of the few remaining copper EW starter-sheet operations in the world. According to the global copper EW survey of 2022, approximately 75% of operations surveyed made use of permanent cathode technology (Sole et al., 2022). Most larger-capacity operations employ permanent cathodes, which decrease labour intensity and allow for significant automation. Being a starter-sheet operation with technology that was adopted in the 1980s, the dependency on manual labour to execute activities is crucial in ensuring that the BMR plant purpose and performance measures are satisfactorily met.

Prior to the 2011 expansion, RBMR operated a combined nickel and copper EW tankhouse. This original tankhouse consisted of three EW bays (West, Centre, and East), each with a dedicated rectifier. Two bays (Centre and East) were used for nickel EW and one bay (West) was used for copper EW. The expansion necessitated construction of a new nickel tankhouse and the old tankhouse became dedicated to copper EW. Copper production capacity was increased by converting Centre Bay from nickel to copper EW cells, whilst East Bay was decommissioned. Current copper EW operation employs the West and Centre Bays.

Following leaching and purification, in which the BM are dissolved into solution and primary impurities removed, the copper solution, known as copper advance (CuAdv), is fed to the copper tankhouse. A direct EW process is employed, where the feed to the tankhouse originates directly from the leach, i.e., there is no intermediate solvent-extraction step, which is typical of most modern copper hydrometallurgical flowsheets. The electrolyte fed into the cells comprises fresh CuAdv mixed with the recirculating copper spent electrolyte (CuSP) stream. The volumetric flow is controlled via advanced process control, with the primary aim of managing inventory volume between the copper tankhouse and leaching plant. The copper feed electrolyte is passed through a Scheibler polishing filter to reduce any residual solids content, then fed to the banks of individual cells via multiple carousel feeding systems. Figure 2 illustrates the high-level process flow of the copper tankhouse.

Improving performance at Rustenburg Base Metals Refiners copper tankhouse

In addition to plating out copper from solution to cathodes, the copper tankhouse is essential for the associated generation of sulfuric acid and cupric ions (Cu^{2+}) that are returned to the leaching plant as CuSP; thus, not all copper in the feed to the tankhouse is plated to final cathode. The cupric ions and acid present in the CuSP are utilised in the primary leach stage and the acid is used in the secondary leach stage. Performance and running of the tankhouse are consequently necessary for operation of the leach circuit.

In comparison with the other RBMR and PMR products, copper contributes only a small percentage of production and revenue to AAP. As a consequence, copper EW was traditionally regarded as a sacrificial process within the refinery, and considered the 'Cinderella' tankhouse. Since 2020, however, a concerted operational effort has been made to improve its performance to world-class standards for a starter-sheet operation. This was done by reviewing operational strategies, using prior industry experience, consulting global best practice, and fundamentally going 'back to basics' as tools to guide improvements in production and quality. This article describes the achievements and outcomes of these interventions.

Review of process performance

Tankhouse capacity, performance, and operability, in both its previous and current states, are highly dependent on operational excellence. The journey towards improving plant operability and cathode quality in a labour-intensive environment was not easy. Operational discipline, consistency, and ensuring that the basics required for an EW operation from all levels of work are performed and monitored, were essential to seeing change. An operational review of the tankhouse for the 2018–2024 period, detailing production output, plant current efficiency, production quality, and operational challenges, is presented.

Copper production

The copper tankhouse has transitioned from an era of being unable to consistently achieve production targets, due to various operational challenges, to now sustainably producing copper at the desired quality. Monthly and annual cumulative production are shown in Figure 3.

The nameplate capacity equivalent of the copper tankhouse is 20.6 kt/a, based on the RBMR feed Ni:Cu ratio in WCM of 1.57 and nickel tankhouse design capacity of 32.4 kt/a. Although nameplate production has not been reached, owing to low feed availability, the copper tankhouse has produced > 10 kt/a for the past six years, except for events in 2020 primarily related to the global pandemic. The 2020 period presented multiple challenges in the tankhouse environment to preserve equipment and place the operation in care and maintenance. Following resumption of normal operation, significant challenges were experienced in the journey to achieve desired production and quality targets. In the past six years, the tankhouse produced the highest monthly copper production of 1305 t in August 2024.

Current efficiency and current density

The target current efficiency for the starter-sheet tankhouse is 88%. Figure 4 illustrates the tankhouse operational current efficiency. Prior to 2021, target current efficiency was seldom achieved. This was due to various challenges, including poor quality of cell maintenance, deteriorated cell-top furniture, impurities in feed electrolyte, poor current distribution, backlogged and inadequate cell cleaning and maintenance strategies, and overarching inferior operational discipline. Poor adherence to anode-replacement lifecycles and no close visibility of anode ages resulted in the use of depleted Pb–6%Sb anodes, where thicknesses were described as 'paper-thin'. The operation consequently incurred increased operational expenditure to purchase large batches of new anodes for improved performance from late 2019. Challenges along the journey, from learnings in plant experience to improved performance, are summarised in the fault tree depicted in Figure 5.

Following recovery from the 2020 period, the tankhouse managed to consistently achieve monthly current efficiencies exceeding 88%, and sometimes 90%. This is attributed to improved operational discipline and a focus on basics. Deviations from target current efficiency in late 2022 to early 2023 were attributed to a brief period of high Fe in the copper circuit (where the chemical impact—current consumption attributed to the oxidation–reduction cycling of the Fe(II)/Fe(III) couple in the electrolyte—was exacerbated by the physical impact of cathode straps breaking), followed by a period of low copper concentrations in electrolyte emanating from the leach plant. Frequent plant stop/starts and a higher frequency of running on trickle current during this period

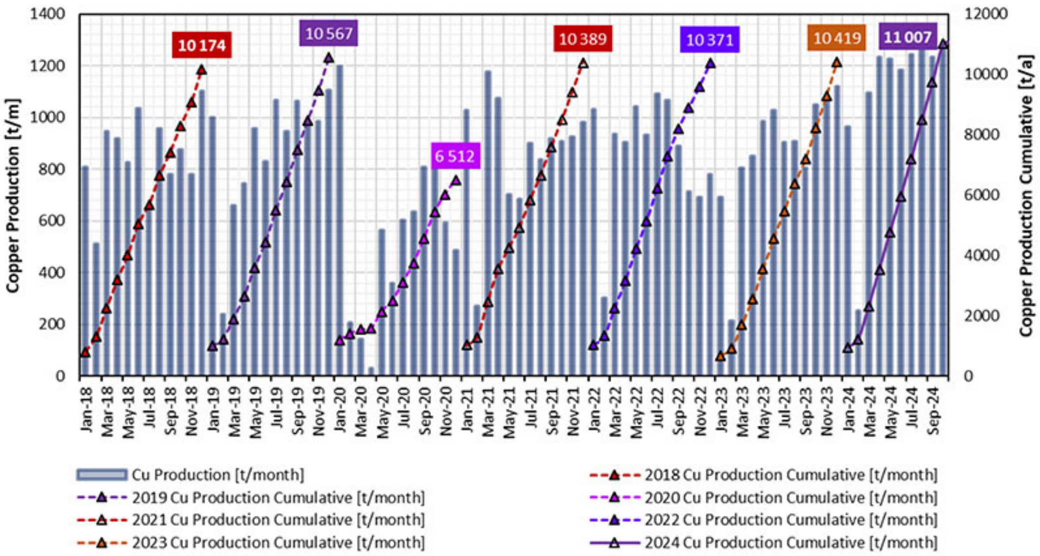

Figure 3—Copper production at Rustenburg Base Metals Refinery copper tankhouse for the 2018–2024 period

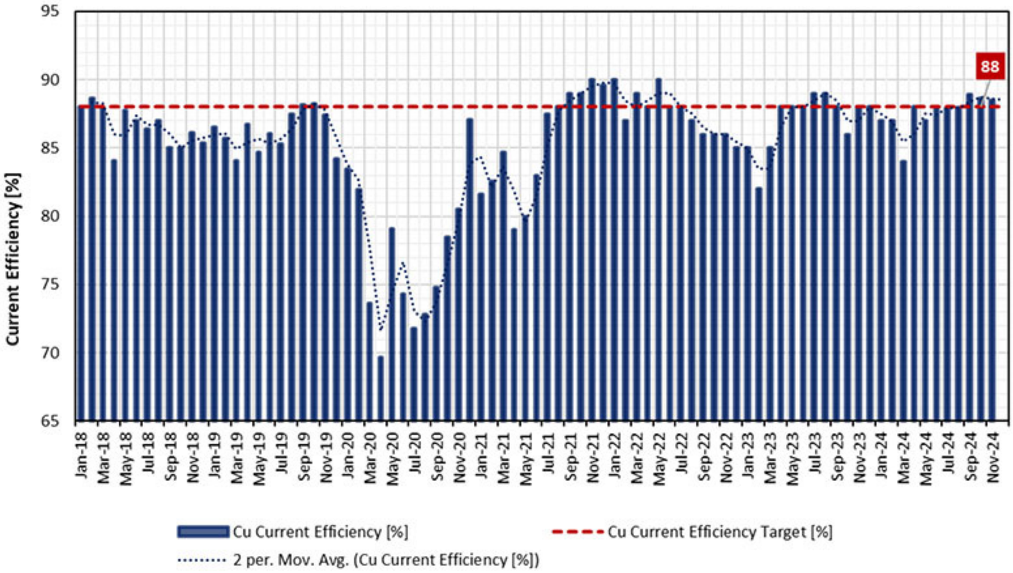

Figure 4—Current efficiency at Rustenburg Base Metals Refinery copper tankhouse for the 2018–2024 period

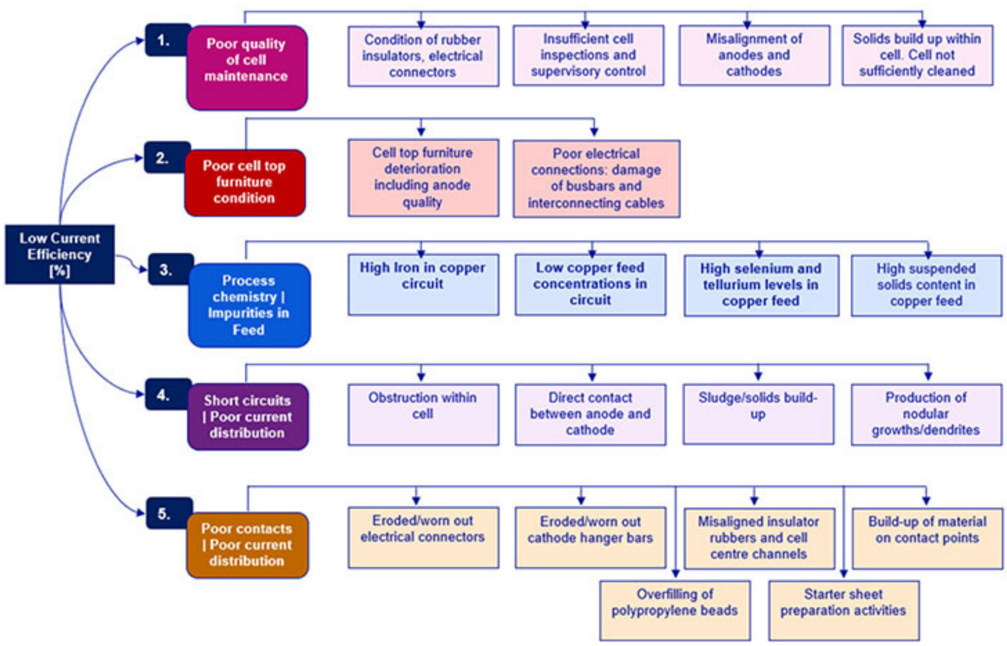

Figure 5—Root-cause analysis fault tree indicating likely reasons for poor current efficiency in the copper tankhouse

further affected continuous plant run time and performance. Breakthroughs of selenium and tellurium to the tankhouse in December 2022 to January 2023 also contributed to poor current efficiencies and poor cathode quality. The annual plant shutdown takes place in February, so March of each year typically results in lower current efficiencies as the operation ramps up and stabilises.

The maximum operational current densities are 220 A/m^2 and 140 A/m^2 for West Bay and Centre Bay, respectively, as limited by the respective rectifier inputs of 13 kA and 16.5 kA. The RBMR copper tankhouse is regarded as a low current density, high-'bite' operation compared with other operations, which typically operate at 300–450 A/m^2 (Sole et al., 2022). RBMR also has a lower cathode specific flowrate compared with most operations. The applied current input to the tankhouse is a function of the copper concentration of the feed electrolyte and the Cu^{2+} and H_2SO_4 concentrations in the CuSP required for the upstream leach plant. The difference in copper concentration between the feed and spent electrolytes (ΔCu) is a function of the number of cells online at the tankhouse. It is not ideal to consistently operate at maximum applied current; minimising and smoothing of rectifier set-point movements are desired when these can be accommodated.

Copper quality

Achieving good quality final copper product is significantly related to the operational activities required to maintain good current efficiency. From the various challenges outlined prior to 2021, significant improvements to the high-impact factors of cell cleaning and maintenance, improved fault checking and rectification, cell electrolyte-level compliance, and feed checks, significantly contributed to achieving good copper quality.

Scrap rate

Copper cathode at RBMR is marketed as Rustenburg (RTB) Grade, based on both physical and chemical properties. Copper cathodes are classified as Grade 1 (meet chemical specification and have good surface quality), Grade 2 (meet chemical specification and have fair surface quality), and Grade 3 (meet chemical specification and have low surface quality). A comparison of the chemical specification of RTB Grade copper with London Metal Exchange (LME) Grade A is shown in Table 1. Copper that does not meet this specification is classified as B Grade (poor surface quality, with excessive nodulation and dendrite growth), PQ Grade (poor quality; mossy copper), or scrap (off-cuts and scrap starter sheets, which are inherent to starter-sheet technology). Cathodes that have fallen into cells and recovered during cell cleaning and maintenance contribute to scrap production.

The scrap rate is defined as the percentage of all non-RTB Grade copper to total copper production. This includes all copper produced and available to market other than RTB Grades 1, 2, and 3. The events of 2020 resulted in high scrap rates, owing to challenges in timeous harvesting, producing poor quality starter sheets, and backlogged cell maintenance. Prior to 2023, the target maximum scrap rate (upper specification limit: USL) was 12%. This target was decreased to 10% in early 2023, as consistent, stable, and capable product quality performance was attained. A significant change was the implementation of an energy-based harvest calculator, implemented in 2021, that informed production teams when cells were due for harvesting, based on current accumulation. The harvest calculator tracks individual cells using data retrieved from the online supervisory control and data acquisition (SCADA) system. The use of Faraday's law informs target cathode mass accumulation, which dictates the harvest time of a cell. This informs the production teams exactly when cathodes need to be harvested, or when rectifiers need to be limited for cells that cannot be harvested due to labour constraints or equipment breakdowns, where potential overplating and high current accumulation then become a safety risk. Prior to the use of the energy-based harvest calculator, production teams would harvest cells based on the number of days that a cell had been online, which did not accurately consider plating current or downtime. Furthermore, work shifts were assigned specific cells for which they were responsible—any challenge regarding labour or cell maintenance that prevented on-time harvesting was detrimental. Late harvesting of cathodes resulted in excessive nodular and dendrite growth that affected morphological appearance, and thus, physical quality. Starter cells were more severely affected when harvested late, because these sheets proved too thick and heavy for preparation into starter cathodes and were consequently graded as scrap. Cathodes that were harvested too early resulted in a light off-specification product, which had to be regraded because it did not meet market requirements.

A key sustainability imperative to good quality starter-sheet production is the supply of sufficiently stocked and available buffed titanium blanks. The use of titanium blanks in the starter cells at the tankhouse is a historic artefact. The conditional exchange of blanks from starter cells is important due to the formation of an insulating titanium hydride layer along the edges of the blanks that causes poor plating along the blade surface. This results in undersized starter sheets that cannot be used in the starter preparation process and are ultimately unsuitable for use as starter cathodes in production cells. Poor edge-strip application on blanks and/or failures of edge strips, due to solution ingress or wear, causes copper to fully plate around the edges of the blanks and form nodules at the corners of the blanks, making manual stripping difficult. A new H-type removable edge strip was implemented in 2022, which

Table 1
Chemical specification comparison of LME Grade A and Rustenburg Grade copper cathode

Element	LME Grade A (ppm maximum)	Rustenburg Grade 1 (ppm)	Rustenburg Grade 2 (ppm)	Rustenburg Grade 3 (ppm)
Cu	>99.95%	>99.95%	>99.8%	>99.8%
Se	<2	<10	<30	<50
Te	<2	<6	<6	<50
Bi	<1			
Se, Te, Bi	<3			
Cr + Mn + Sb + Cd + As + P	<15			
Sb	<4			
Pb	<5	<30	<30	<50
As	<5			
Fe	<10	<15	<15	<
Sn + Ni + Fe + Si + Zn + Co	<20			
Ni	<10	<15	<30	<50
Sn	<5			
S	<15	<30	<30	<50
Ag	<25			
Maximum allowable total	<65			

significantly improved edge strip failure rates and made starter-sheet stripping easier. These new edge strips, coupled with the conditional exchange of titanium blanks, led to the production of pristine, on-specification starter sheets, and a reduction in scrap. Implementation of process interlocks on key equipment, such as rectifiers, also prevents poor quality copper. One such interlock implemented is the instantaneous ramping down of rectifiers to trickle current if a cell bank within a bay does not receive any feed. This prevents the production of mossy copper, which is caused by low copper concentrations in the EW cells (in this case, owing to no fresh feed and depleting electrolyte copper concentration) and running at higher applied currents to reduce the copper from the electrolyte to cathode product. The evolution of scrap-rate improvement is illustrated in Figure 6.

The exceptional trend of consistently improving scrap rates from 2020 substantially digressed in late 2022 to early 2023, with the highest monthly scrap rate of 63.40% recorded in February 2023. The poor performance in December 2022, which carried over to January 2023, was attributed to breakthrough of selenium and tellurium to the tankhouse, owing to inadequate upstream removal of these elements. The higher levels of these impurities reporting to the electrolyte (> 45 mg/L Se, Te; target of < 25 mg/L in feed) affected an entire plating cycle, where cathodes failed on both chemical (> 150 ppm Se, Te; target of < 50 ppm in cathode) and physical (black powdery deposit) specifications. Although the initial upstream cause was corrected, cathodes that were in the plating cycle then passed on physical specification but failed on chemical specification due to already-plated selenium compounds in cathode, causing this impurity excursion to impact several plating cycles.

Following the February 2023 annual shutdown, an entire plating cycle produced mossy copper. This was attributed to a depletion of copper in the CuSP, owing to operating at higher trickle currents during the tankhouse shutdown. Owing to shutdown maintenance on the feeding circuit, the cells could not be topped up with fresh feed. The trade-off required between preserving the protective oxide coating of the lead-alloy anodes in sulfate-based solution by application of a trickle current and depleting of copper in the CuSP became glaringly apparent. A shutdown current calculator was subsequently developed that considers the minimum current required for anode preservation. This initiative, together with strict cell sampling campaigns during shutdowns to inform rectifier set points, led to an acceptably low scrap rate of 8.42% during the February 2024 shutdown.

Improvements and causes in scrap-rate performance from plant learnings and experience are summarised in the fault tree depicted in Figure 7.

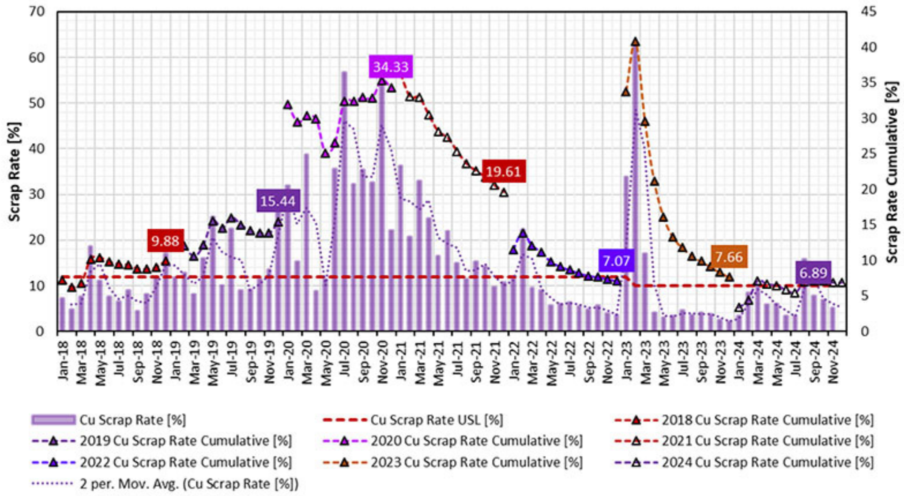

Figure 6—Copper scrap rate at Rustenburg Base Metals Refinery copper tankhouse for the 2018–2024 period

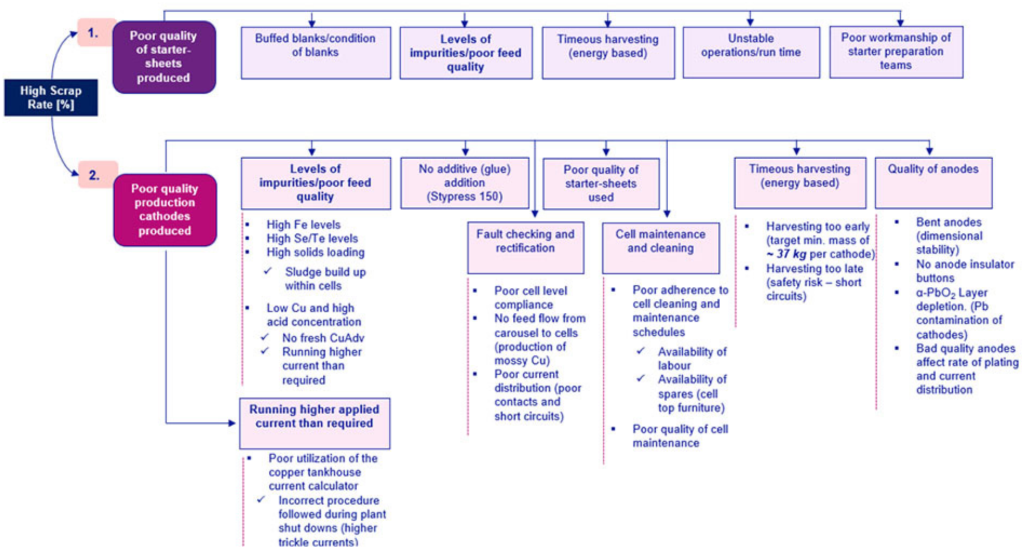

Figure 7—Root-cause analysis fault tree indicating likely reasons for high scrap rates

Copper grading

The RBMR copper grade has significantly improved since 2018, coming from an era of frequently producing poor-quality copper and excessive scrap. The improvements, metrics, and a focus on basics in the EW environment have translated to a period of best performance in the history of the tankhouse. Production targets at good quality are consistently achieved, with a record low scrap rate of 2.06% in December 2023. Figure 8 illustrates the evolution of copper production grading from the tankhouse since 2018.

The improvements in production quality are depicted in Figures 9 to 11, where smooth copper with minimal nodulation and dendrite growth can be seen, in comparison with poor-quality

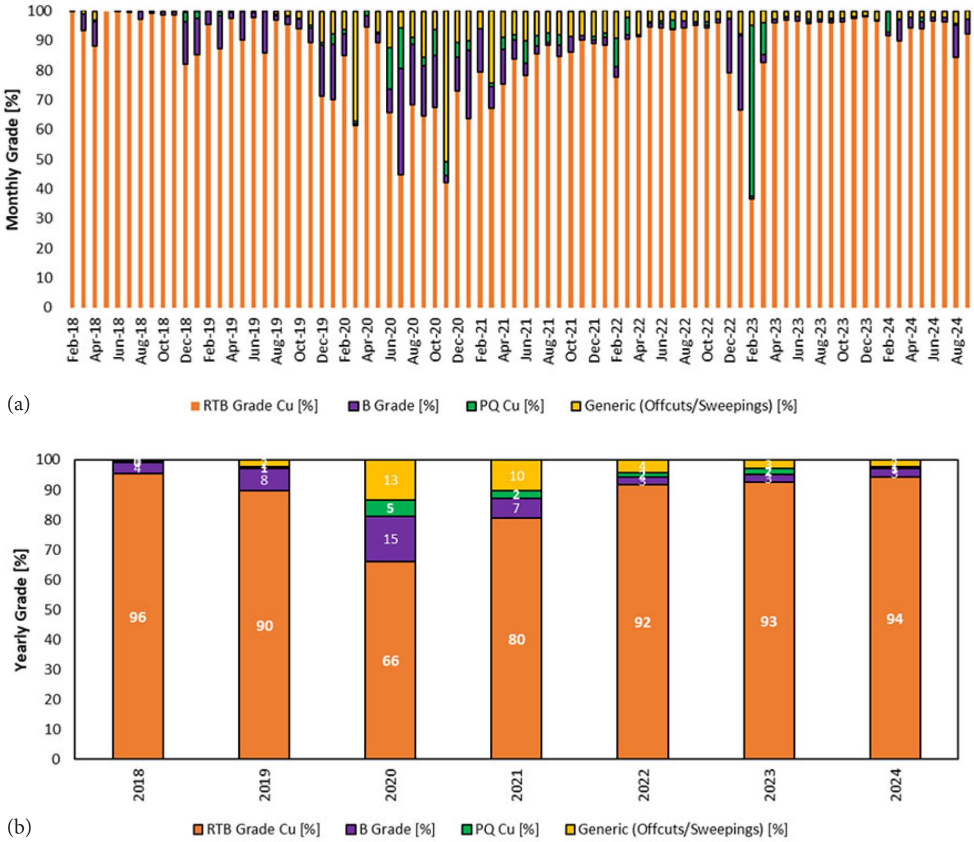

Figure 8—(a) Monthly and (b) annual copper grading at Rustenburg Base Metals Refinery copper tankhouse for the 2018–2024 period

Figure 9—Poor-quality mossy copper, with excessive nodulation, and the effects of high selenium and tellurium impurities

Figure 10—Effects of short circuits on copper cathode production owing to inadequate fault checking and rectification, leading to excessive nodulation and dendrite growth

Figure 11—Good quality, smooth copper cathode with minimal nodulation, defects, and dendrite growth

Figure 12—Comparison of poor-quality (mossy copper) production frequently achieved prior to 2021 with present, high-quality production

copper with excessive nodulation that was routinely produced in the past. Figure 12 compares the typical RBMR mossy copper quality that was produced prior to implementation of the aforementioned operational improvements with the current quality sold to market.

Cathode analysis

Final cathode quality analyses for the main impurities (selenium, tellurium, iron, lead, sulfur, and nickel) and copper purity are shown in Figure 13. Today, RBMR consistently achieves > 99.9% copper purity. The effects of the selenium and tellurium breakthroughs manifest as spikes in these assays, causing the cathodes to fail on chemical specification. Notable improvements in cathode impurity levels are evident from late 2021 with respect to variation in the data, particularly for iron, lead, sulfur, and nickel.

Conclusions

Targeted operational interventions, informed by global best practice and grounding to fundamentals, coupled with the development of quantitative decision-making tools, have yielded significant improvements in production, efficiency, and quality at the RBMR copper starter-sheet operation. These directly reflect the tankhouse operational strategy and discipline. The main achievements are summarised in the following:

- ➤ The RBMR copper tankhouse has produced more than 10 kt/a of copper cathode since 2018, except for the year 2020, during which production declined owing to the Covid-19 pandemic and associated operational interruptions.
- ➤ Improvements in adherence to basic operational practices and key sustainability measures, such as the frequency and quality of cell cleaning and maintenance, prevention of backlogged and inadequate maintenance strategies, preserving acceptable cell-top furniture conditions, integrity of electrodes, preventing poor current distribution, and operational discipline, significantly contributed to an era of great performance.
- ➤ The high-impact factor of cell cleaning and maintenance has contributed to improved performance of EW cells. Ensuring that maintenance schedules are diligently completed contributes to higher current efficiencies.
- ➤ The use of an energy-based harvest calculator has allowed for timeous harvesting of production.
- ➤ H-type edge strips on starter blanks have resulted in the production of good quality starter sheets.
- ➤ Current efficiency significantly improved from 2021, consistently achieving monthly efficiencies exceeding 88%, with a highest monthly value of 91%.
- ➤ A historic monthly low record copper scrap rate of 2.06% was achieved in December 2023, which was previously believed to be limited to a minimum of 4%.
- ➤ Physical quality has improved considerably, with minimal dendrite growth, mossy copper, and reduction in excessive nodulation.
- ➤ Final cathode analyses for the main impurities (Se, Te, Fe, Pb, S, and Ni) have shown notable improvements with respect to variation in the data since 2021, particularly for Fe, Pb, S, and Ni. Cathode exceeding 99.9% purity is consistently produced.
- ➤ The RBMR copper tankhouse operation has achieved performance stability and capability consistent with the target production and quality measures.

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CRediT author statement

KN: Methodology, investigation, analysis, visualisation, validation, project administration, writing - original draft preparation; MP: Supervision, resources; JH: Conceptualisation, funding acquisition; KCS: Supervision, writing – review and editing.

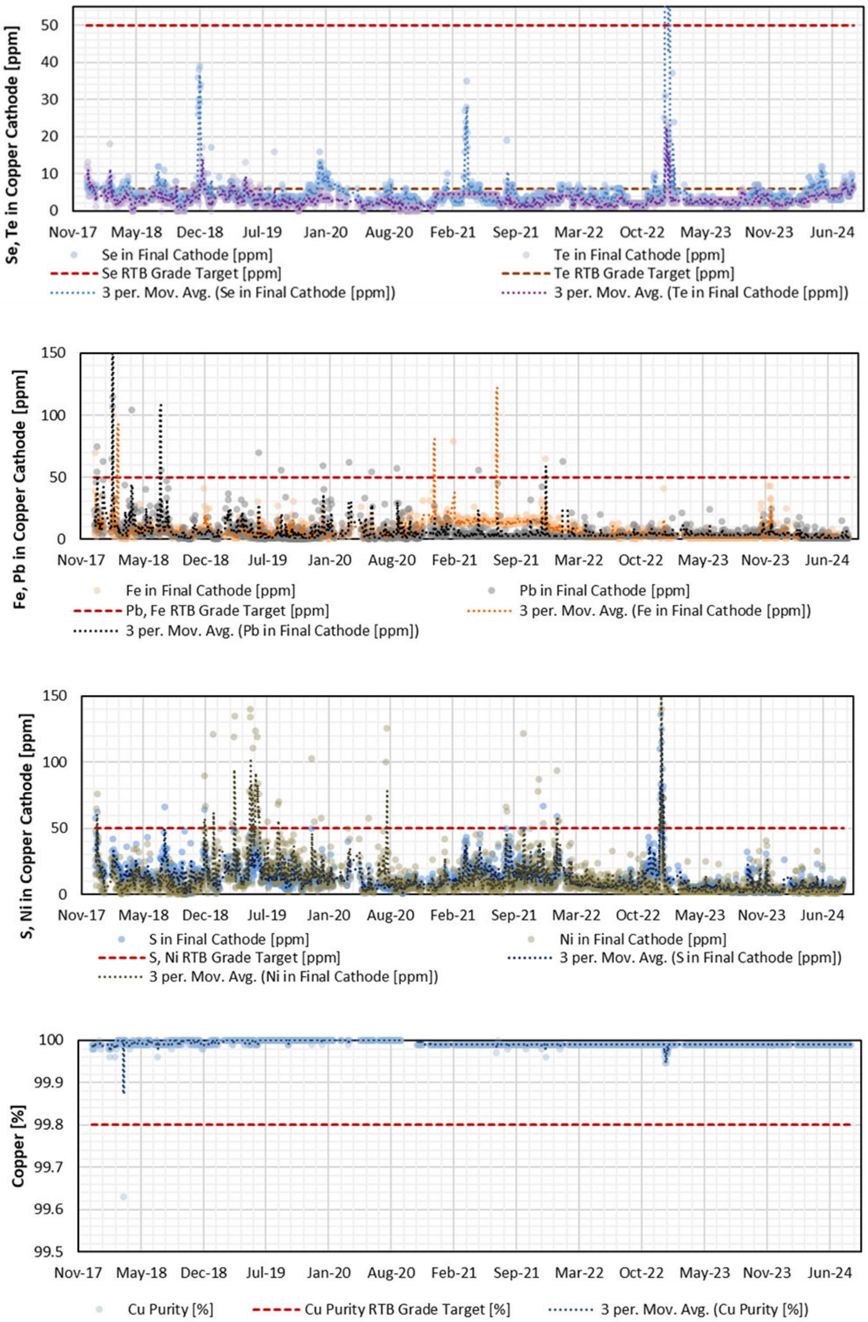

Figure 13—(a) Selenium and tellurium, (b) iron and lead, (c) sulfur and nickel, and (d) copper analyses of final copper cathode

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