Refinery effluent water reduction and treatment

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Abstract

This article outlines various projects implemented at Rand Refinery to reduce effluent generation and freshwater consumption. The refinery generates about 2800 m^3 of effluent annually and has initiated projects such as granulation water recycle and silver leach optimisation to address these issues. The granulation water recycle project has successfully reduced effluent volumes, while the silver leach optimisation has further decreased effluent by implementing stoichiometric addition of HCl and $NaClO_3$. The vibratory shear enhanced processing (VSEP) trial showed promising results for gold recovery from wastewater, though further trials are recommended. The water savings of the effluent reduction projects are monitored by measuring the amount of effluent pumped to service yard effluent storage facilities with the use of flow meters connected on SCADA. Since the effluent reduction initiative of granulation effluent recycle in FY23, the effluent reduced to 2676 m^3. In FY24, the stoichiometric addition of HCl and $NaClO_3$ was implemented in the silver leach process, further reducing the effluent to 2083 m^3.

Keywords

refinery effluent, granulation water recycle, vibratory shear enhanced processing (VSEP), silver leach optimisation, gold recovery, effluent management, resource conservation, environmental, social, and governance (ESG), fresh water consumption reduction

Introduction

Rand Refinery (Pty) Limited, established in 1920, is the world's largest integrated single-site precious metals refining and smelting complex. It refines gold within South Africa, handling mine dore' deposits, jewellery scrap, and alluvial deposits with gold content ranging from 10% to 99%. The refinery employs three main technologies for refining gold and silver: Miller chlorination, gold electrolysis, and silver electrolysis, focusing on achieving 99.99% purity for gold (Au), and silver (Ag) and producing platinum group metals (PGMs), mainly Pt and Pd, containing sludge for sale (Figure 1).

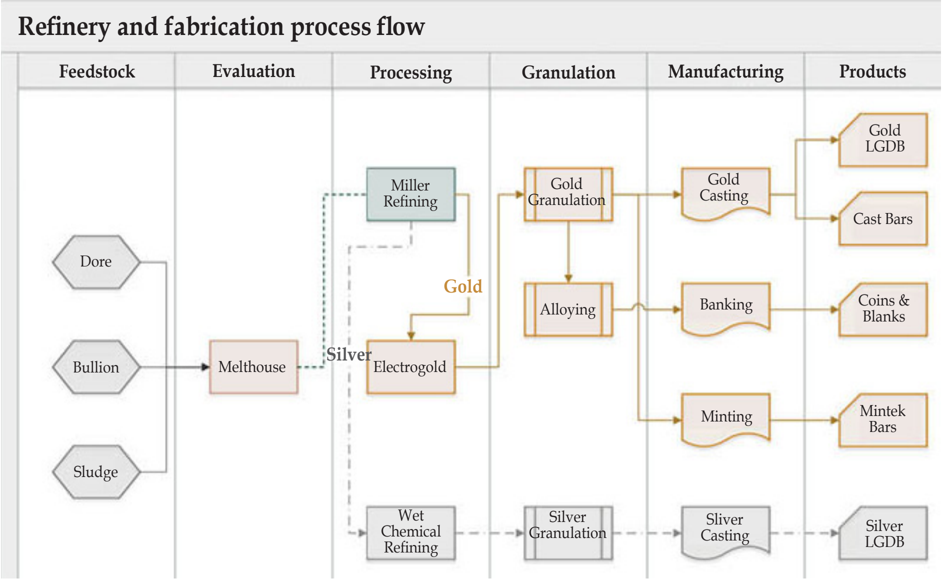


Figure 1—Refinery process flow

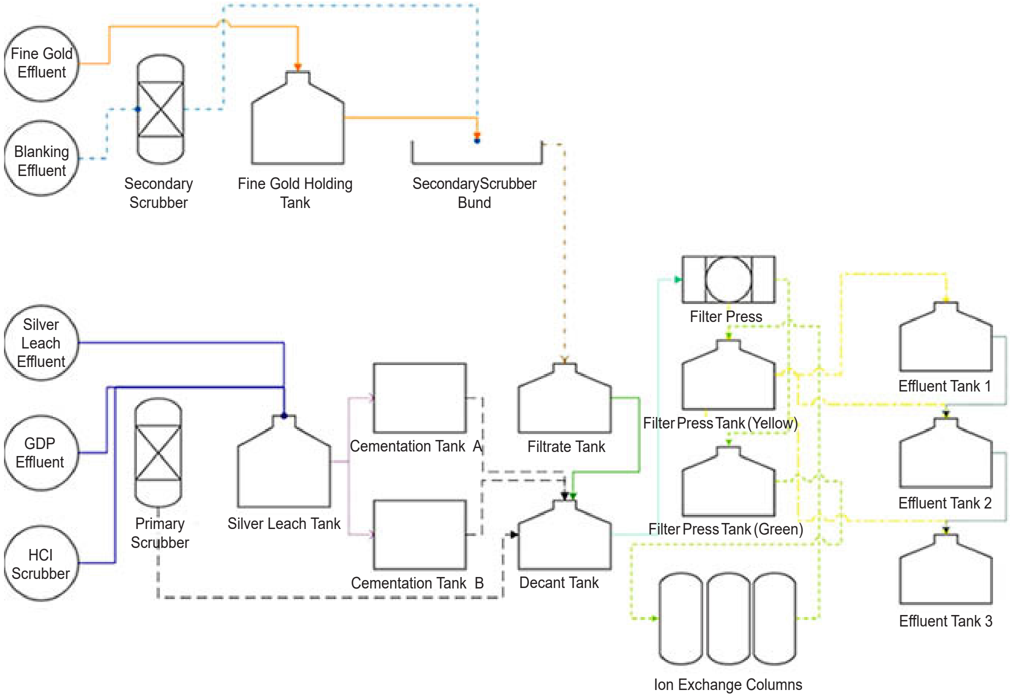


Figure 2—Effluent flow

Effluent is generated from silver leach, gold refining, off-gas fumes scrubbing processes, and general processes such as granulation, quenching, and housekeeping. Between 2019 and 2023, the refinery generated about 2800 m^3 of effluent per year on average, with limited recycling options, leading to high freshwater consumption. The target product quality of 99.99% on most products limits recycling options, as any trace element can lead to quality failure. The effluent is filtered for solids collection, passed through ion exchange resin for further polishing, and sent to an external company for treatment and disposal (Figure 2).

Several projects have been initiated to reduce effluent and freshwater use, contributing to environmental, social, and governance (ESG) compliance, focusing on natural resource conservation and waste management.

Rand Refinery, with its 103-year heritage, has refined over 56,000 metric tons of gold, accounting for 26% of the gold produced to date on earth. As a member of the London Bullion Market Association (LBMA) and with international accreditations, Rand Refinery adheres to best practices in ESG compliance.

Rand Refinery's ESG strategy aims to meet existing and upcoming regulations and demands, responding to climate change, societal risks and challenges while ensuring sustainable business practices. The journey to ESG maturity involves connecting various frameworks such as the UN Sustainable Development Goals (SDGs), LBMA Responsible Gold Guidance (RGG), and OECD Due Diligence Guidance, guiding the company's strategy in aligning business operations with global ESG objectives.

Rand Refinery has set clear deliverables for the next five years, focusing on decarbonisation and energy projects, waste and effluent reduction, water recycling and reuse, sourcing integrity platform – Gold Bar Integrity, community development, and skills development.

The ESG strategy offers several strategic benefits, including improved reputation and brand value, long-term sustainability and resilience, innovation and efficiency, regulatory compliance, and enhanced stakeholder engagements. These benefits contribute to the company's overall goal of maintaining its legitimacy, credibility, and trust in the marketplace.

Firstly, the ESG strategy significantly improves Rand Refinery's reputation and brand value, enhancing customer loyalty and trust. Secondly, it encourages long-term sustainability and resilience by focusing on resource management and waste reduction. Innovation and efficiency are also key benefits, with the adoption of best-in-class operating efficiency standards and the development of new technologies and procedures. Regulatory compliance is another important aspect, with dedicated personnel examining required changes and offering appropriate advice. Lastly, the ESG strategy emphasises stakeholder engagement, building positive relationships with all key stakeholders through openness and transparent communication.

These strategic benefits collectively contribute to Rand Refinery's legitimacy, credibility, and trust in the marketplace, ensuring the company's long-term success and sustainability. Rand Refinery's commitment to ESG is not just about compliance but about creating value and ensuring a sustainable future. The company's efforts in safety, health, environment, governance, and community engagement are integral to its business operations and reputation.

Methodology

Rand Refinery launched multiple projects, including evaluating the potential to extract additional gold and silver from various sources and devising techniques for water recycling to cut down on Rand Water costs. These activities primarily consisted of internal initiatives and testwork, although some involved assessing both existing and new technologies from suppliers. Here is a summary of these efforts.

Primary scrubber solution testwork

A filtration testwork was conducted to determine the filtration characteristics of the scrubber solution under pressure filtration conditions to enable possibilities of recirculation of the effluent back to the scrubber. Scrubber solution samples were collected to conduct analysis on the following:

- ➤ Slurry density
- ➤ Feed solids
- ➤ pH
- ➤ PSD
- ➤ Temperature.

The test was conducted using the following methodology: The agitated slurry was fed into the filter press using a diaphragm pump, with a predetermined slurry feed pressure applied. A timer was started simultaneously with the pressure application. The cake formation time was recorded when the last of the liquid passed through the surface of the cake, making it visible. The filtrate flow rate was reduced to approximately 10% of the initial flow rate. During filtration, the cumulative mass of discharged filtrate was recorded. After formation, the cake was subjected to a membrane squeeze, with the cumulative mass of discharged filtrate recorded over time. The cake was then collected, and its wet mass and thickness were measured before being oven-dried to determine its moisture content.

Granulation water recycling testwork

A feasibility study was carried out to quantify the effluent produced during the refinery process. Following this, an effluent sampling test was performed, where samples from various effluent streams were collected to examine their properties and pH levels. The pH analysis was conducted using a pH probe meter, while ICP-OES and titration methods were employed to determine the trace elements present in the effluent.

Silver leach stoichiometric addition

Testing was carried out to examine the feasibility and impact of total oxidation in silver leach operations by incorporating the necessary stoichiometric amounts of HCl and $NaClO_3$ during the oxidation phase. To ensure complete oxidation and decrease the number of HCl wash stages, an optimal copper concentration was established before the silver leach process. This was done to safely introduce the required stoichiometric quantities of HCl and $NaClO_3$ into the silver leach reactors without risking overly vigorous reactions.

Vibratory shear enhanced processing techniques

The pilot study at Rand Refinery in Germiston involved running the VSEP pilot plant in batch mode on three waste streams: silver, primary scrubber, and fine gold. Samples were collected in 1000 L flow bins, and a smaller quantity was fed to the VSEP feed flow bin tank. A line out was conducted at 50psi to condition the membranes, followed by a pressure study at various pressures to determine the optimum operating pressure. The batch test run aimed to concentrate gold and other minerals for recovery by separating particulate materials into two streams. The concentrate stream had a high total suspended solids (TSS) value, while the permeate stream had a much lower suspended solids content.

The permeate stream was removed and fed to a permeate storage tank, while the concentrate was recycled back to the feed tank. This process continued until the membrane could no longer process the stream, and the flux began to decline. After each run or day, the system was cleaned using cleaning chemicals and water flushes. The pilot plant setup included the feed flow bin, VSEP skid with membrane pack, CIP tank, and permeate flow bin. The membrane pack, piping, feed pump, and vibratory motor were essential components of the system. During the trial, 19 membrane and diverter trays were used, but due to malfunctioning, a damaged membrane tray and one diverter tray were removed after processing the silver stream effluent, leaving 17 trays for the remaining runs.

Results and discussion

Effluent data collection

For context, Tables 1 and 2 provide a summary of the effluent data for both the gold and silver effluent streams. The effluent output data for the fiscal years 2022 to 2024 show a general trend of reduction, with some fluctuations. In FY 2022, the effluent output was relatively high across all quarters. In FY 2023, there was a

Table 1

Fine gold effluent to central effluent plant

Quarter	Effluent Output (kl) for FY 2022	Effluent Output (kl) for FY 2023	Effluent Output (kl) for FY 2024
Quarter 1	243.24	272.73	173.62
Quarter 2	269.36	222.32	181.61
Quarter 3	237.10	225.62	281.37
Quarter 4	242.69	161.10	129.90

Table 2

Silver plant effluent to effluent central plant

Quarter	Effluent Output (kl) for FY 2022	Effluent Output (kl) for FY 2023	Effluent Output (kl) for FY 2024
Quarter 1	313.96	236.02	264.76
Quarter 2	285.62	194.36	195.78
Quarter 3	207.98	195.31	229.68
Quarter 4	255.73	208.93	172.19

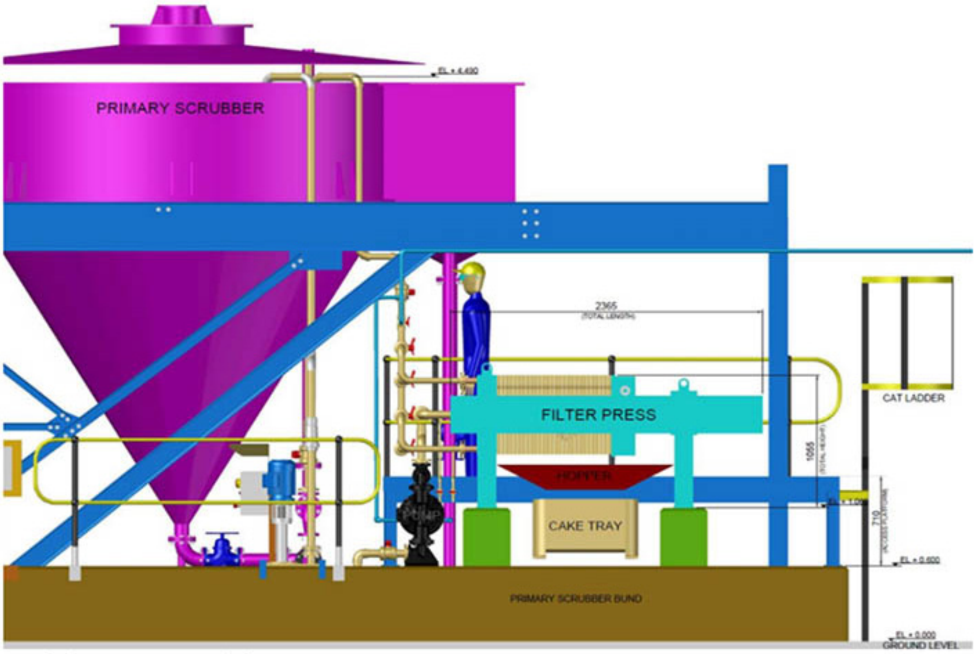


Figure 3—Primary scrubber 3-D model

noticeable reduction, particularly in Quarter 4 (161.10 kl), which coincides with the start of the granulation recycling work on 29 July 2023. This trend continued into FY 2024, with significant reductions in Quarter 1 (173.62 kl), Quarter 2 (181.61 kl), and Quarter 4 (129.90 kl). However, there was an increase observed in Quarter 3 of FY 2024 (281.37 kl), indicating some variability in the effluent output over the years, which was caused a floor repairs project conducted on the granulation water recycle circuit area.

The effluent output data for the silver streams over the fiscal years 2022 to 2024 shows a general trend of reduction, with some fluctuations. In FY 2022, the effluent output was relatively high across all quarters, with Quarter 1 having the highest output at 313.96 kl. In FY 2023, there was a noticeable reduction in effluent output, particularly in Quarter 1 (236.02 kl) and Quarter 2 (194.36 kl), which coincides with the start of the silver leach stoichiometric testwork on 1 December 2022. This trend continued into FY 2024, with further reductions in Quarter 2 (195.78 kl) and Quarter 4 (172.19 kl). However, there were some increases observed in FY 2024, specifically in Quarter 1 (264.76 kl) and Quarter 3 (229.68 kl), indicating some variability in the effluent output over the years, this which was caused by floor repairs in the fine gold area, the effluent recycle area was off to allow the floor repair project to be completed. During this period all the high-pressure wash activities were conducted in the silver plant with clean water.

Primary scrubber solution testwork

The Miller chlorination process generates chlorine fumes that contain trace amounts of gold and silver in the dust. These fumes are processed through a chlorine scrubber system, which uses caustic soda to neutralise the gaseous chlorine and capture the metal particles. The system consists of two sequential scrubbers—a primary and a secondary. The primary scrubber captures most of the metal particles in a caustic solution, while the secondary scrubber ensures complete neutralisation before the gases are released into the environment. The collected metal particulates in the scrubber solution are filtered monthly using a central filter press for metal accounting.

Due to limited recycling options, filtering the scrubber solution resulted in approximately 20 m^3 of effluent being disposed of monthly via an external company, necessitating freshwater additions to the scrubber. To resolve this, a project was initiated in 2019 and completed in 2020 to install a dedicated filter press for the primary scrubber, allowing the scrubber filtrate solution to be recycled back into the primary scrubber. The advantages of this initiative include:

➤ Reduced handling and treatment of effluent since the filtrate will be recirculated.
➤ Continuous filtration and recovery of metal particles, improving daily metal accounting.
➤ Enhanced scrubber efficiency with ongoing removal of metal particles, increasing the solid loading capacity of the scrubber solution.

Currently, the main scrubber is drained every three months for metal accounting, saving about 160 m3 annually, which reduces treatment costs by roughly half a million rands. Figure 3 presents a 3D model of the primary scrubber filter press, illustrating the layout of the filter press in relation to the primary scrubber.

Granulation water recycling testwork

Effluent generated from various processes, such as silver and gold granulation, scrap cleaning, ducting washing, and melthouse sump, is first gathered in a fine gold effluent tank for preliminary filtration. It is then transported to a central effluent plant for further filtration and polishing disposal (see Figure 4).

The primary factor behind the increase in refinery output was the implementation of high-pressure wash cleaning for scrap in the fine gold area, along with the granulation process that involved daily production of gold granules. To minimise effluent generated by the fine gold plant, an initiative was introduced to reuse process water from the plants, thereby reducing the consumption of clean water and the effluent produced (Reeves, 2000).

Granulation effluent, identified as a clean effluent with a pH above 6.5, presents minimal risk of material corrosion and is thus suitable for use as process water, especially in scrap metal cleaning,

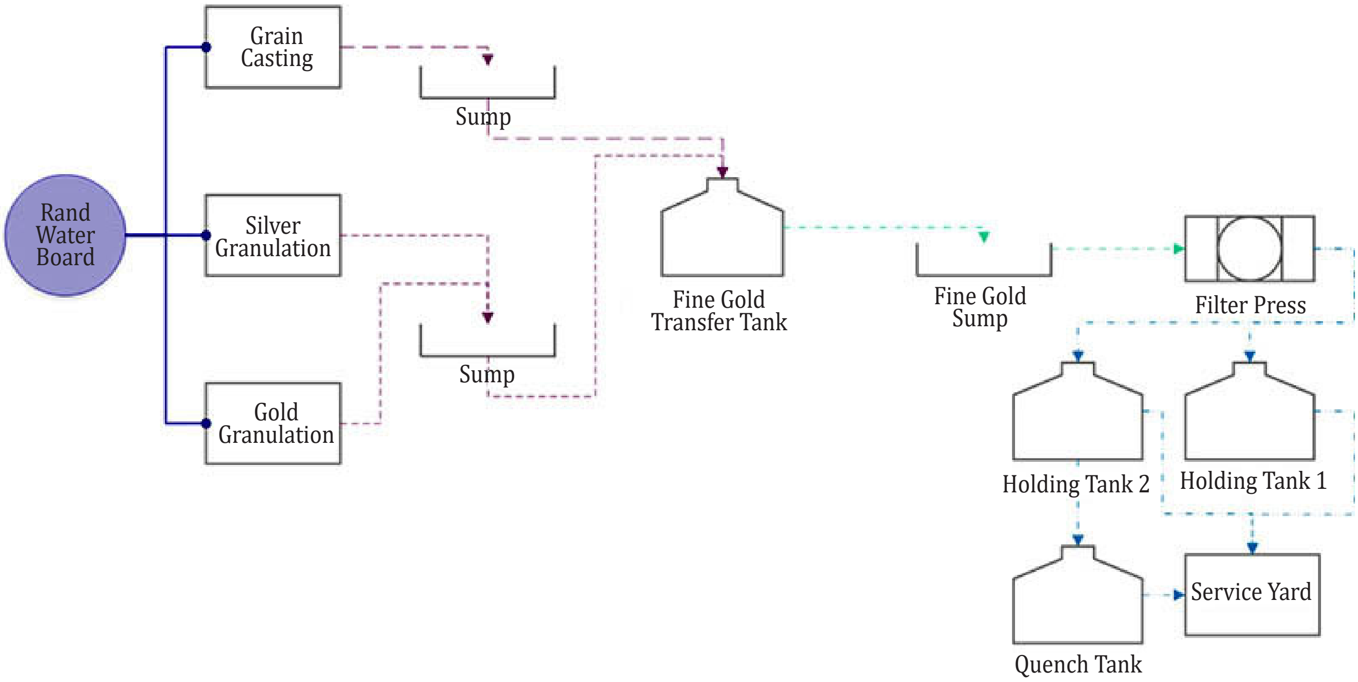


Figure 4—Granulation effluent flow

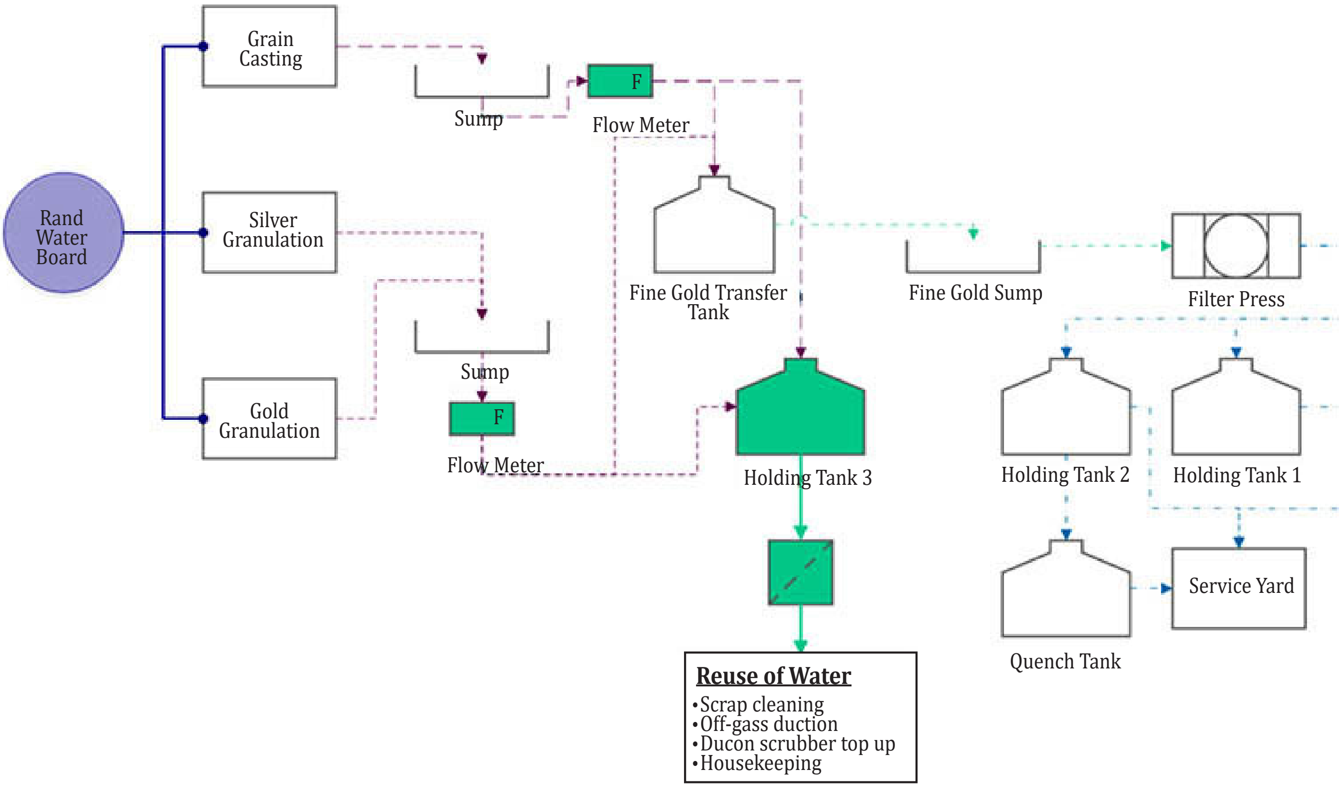


Figure 5—Granulation effluent modified process flow

ducting washing, and silver chloride quenching. Cleaning scrap metal is crucial for ensuring gold contaminants adhere to the scrap, so only clean scrap exits the refinery. Ducting washing is essential for stocktaking, as it removes material buildup in the ducts, which can then be collected through a filter press and treated as part of the recycle stream. Silver chloride quenching involves cooling molten chlorides in water, producing a slurry containing silver chloride that is subsequently processed in a silver leach plant. Historically, these washing processes utilised potable water, resulting in significant effluent generation within the refinery.

A 5000-litre tank was installed to segregate and store the granulation effluent for reuse in less critical areas. This tank features instrumentation controls, including a level transmitter and a high-level switch, to prevent overflows. Two filter housings were fitted in series on the tank's outlet streams, equipped with 25-micron polypropylene Sentinel ring filter bags. These filters ensure efficient removal of solids, protecting sensitive equipment in areas where the effluent will be reused. Figure 5 illustrates the modification in the process flow, highlighting the newly added equipment within the shaded regions.

The refinery has effectively installed and commissioned a granulation water recycling system, which includes a 5000 L tank, a pump, and distribution pipes that supply various areas for tasks such as washing scrap and fine gold fumes ducting (refer to Figure 6). The project was fully operational by 29 July 2023, marking significant milestones like the successful cleaning of fine gold fumes ducting, efficient scrap metal management, silver chloride quenching, Ducon scrubber top and housekeeping improvements.

By August 2024, the amount of effluent released from the fine gold effluent tank to the central effluent plant had dropped by 205 m^3 compared to FY22 (see Figure 7). This decrease represents a cost saving of about half a million rands in effluent treatment expenses.

Silver leach stoichiometric addition

The process of refining gold with chlorine in Miller furnaces generates byproducts like silver and base metal chlorides (Auerswald & Radcliffe, 2005). The molten chlorides produced are transferred using a ladle into a water-filled tank for quenching. This chloride slurry is then directed to the silver leach reactors, which mostly contain copper chloride and other soluble base metal chlorides. Based on the copper content in the feed solution, hydrochloric acid and sodium chlorate are added to the leach reactors. Within these reactors, the slurry undergoes a leaching reaction that converts slightly soluble copper(I)chloride (CuCl) into soluble copper (II)chloride ($CuCl_2$). The reaction is described in Equations 1 and 2.

$$6CuCl(s) + 6HCl(aq) + NaClO_3(s) \rightarrow 6CuCl_2(s) + NaCl(aq) + 3H_2O(l) \quad [1]$$

The reaction mentioned in the aforementioned is exothermic, releasing energy and increasing the solution's temperature. This heat enables a side reaction between HCl and $NaClO_3$, described below.

$$[\![2NaClO]_3 + 4HCl(aq) \rightarrow 2\,[\![ClO]_2\,(g) + NaCl(aq) + H_2O(l) \quad [2]$$

The previously mentioned reaction is endothermic, indicating that it absorbs energy and only proceeds after Reaction 1 has begun in the presence of excess HCl or $NaClO_3$. This reaction is notably intense and can result in a violent release of energy, potentially causing reactor overflow. Efforts to minimise this overflow have led to an increase in effluent production and higher potable water consumption. The ensuing adjustments were identified as the reasons for the elevated use of potable water:

For Reaction 1, HCl and $NaClO_3$ must be added in precise stoichiometric amounts to transform copper(I)chloride (CuCl) into soluble copper (II)chloride ($CuCl_2$). Since accurately measuring CuCl in the chloride feed solution is difficult, it is assumed that all copper is present as CuCl, raising the likelihood of adding excess reagents. To mitigate the risk of runaway reactions due to over-addition, potentially triggering Reaction 2, the team devised an empirical method for the addition of HCl and $NaClO_3$. The empirical approach used several water washes, consistently adding HCl with each wash and monitoring copper levels in the solution. Usually, four washes were needed to reach acceptable copper concentrations, leading to excess effluent.

An additional issue was the inadequate drainage of solution in the reactor. During draining, around 600 L of solution and silver-containing solids remain in the cone of the silver leach reactor. This leftover solution contains copper, which is diluted and removed when fresh, warm potable water is added during the copper leaching and washing stage.

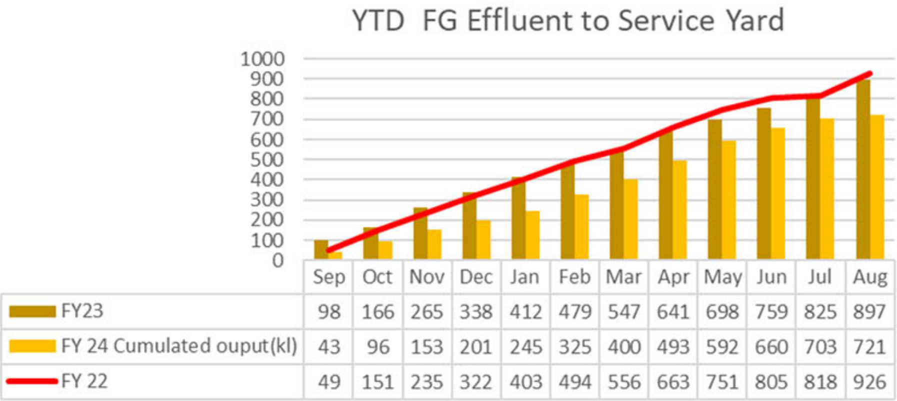
Generally, the reactor is loaded with 1050 liters of solution (450 litres of chlorides and 600 litres of water), resulting in the consumption of 2400 litres of fresh water for four washes per batch. Post-leaching, the effluent is discharged, getting the reactor ready for the zinc reduction phase, which necessitates 600 liters of fresh water.

Each batch uses 3600 litres of water, and with 20 batches processed monthly, the total water usage reaches 72,000 litres per month. To reduce water consumption in the silver leach process, a stoichiometric addition of HCl and $NaClO_3$ will be implemented in a controlled environment designed to prevent Reaction 2 and ensure minimal leftover solution by draining the reactor.

The operational approach has been optimised to enable the stoichiometric addition of HCl and $NaClO_3$ in discrete batches, ensuring precise regulation of pH and temperature. These control measures are designed to minimise the risk of intense reactions associated with Reaction 2. Moreover, supplementary effluent drainage from the cone is utilised to further extract copper from the solution.

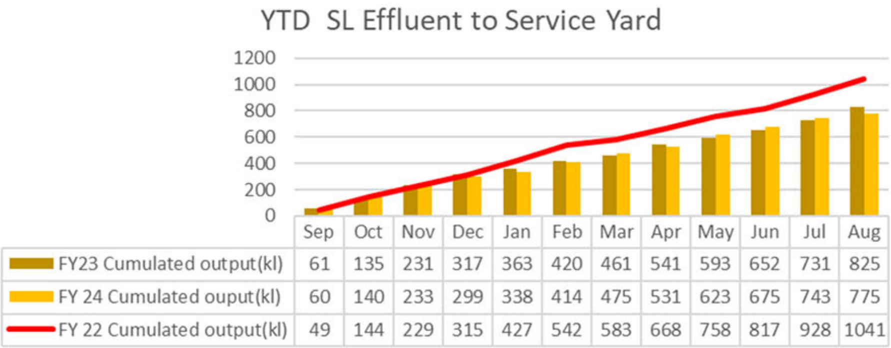
At present, a manual drain decreases the volume to around 400 litres, making sure that no silver solids are removed. Adding HCl and $NaClO_3$ stoichiometrically would cut water usage by 1800 litres per batch, translating to a monthly decrease of 36,000 litres. As shown in Figure 7 this solution has led to an effluent reduction of 266 cubic metres between FY22 and FY24.

Figure 6—Granulation water recycle plant, front and back view



	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
FY23	98	166	265	338	412	479	547	641	698	759	825	897
FY 24 Cumulated ouput(kl)	43	96	153	201	245	325	400	493	592	660	703	721
FY 22	49	151	235	322	403	494	556	663	751	805	818	926

Figure 7—A combined column and bar chart illustrating the Fine Gold effluent directed to the central effluent plant



	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
FY23 Cumulated output(kl)	61	135	231	317	363	420	461	541	593	652	731	825
FY 24 Cumulated ouput(kl)	60	140	233	299	338	414	475	531	623	675	743	775
FY 22 Cumulated output(kl)	49	144	229	315	427	542	583	668	758	817	928	1041

Figure 8—A combined column and bar chart illustrating the silver effluent directed to the central effluent plant

Vibratory shear enhanced processing techniques

The aim of the trial, guided by bench top trials conducted by New Logic Research, was to further assess the potential for removing and concentrating solid mineral particles of gold and silver using the VSEP in batch operation. The pilot trial processed three waste streams from the smelting refinery: silver, primary scrubber, and fine gold. Visual inspection revealed almost no solid particles in the silver stream and fine gold run 2, while the primary scrubber streams and fine gold run 1 were slurry streams.

Pressure studies were conducted by starting the system in recirculation mode at 50 psi (3.5 bar) and increasing the pressure in 10 psi (0.7 bar) increments up to 110 psi (7.6 bar). The flux was recorded at each pressure, with the results indicating a flattening of the curve at 80–100 psi. The trial was run at 110 psi to optimise recovery, although it is recommended to run future trials or full-scale VSEP plants at 100 psi (~6.9 bar) to avoid the potential inverse effect of 'tightening' membrane pores.

The Silver Stream Concentration Study began with the system in recirculation mode at 100 psi (6.9 bar). The permeate line was diverted to the permeate tank, and the batch concentration study commenced. The permeate flow rate was measured at timed intervals, and as permeate was removed, the sample became more concentrated. The test concluded when the flow rate dropped to 10 GFD/17 LMH, achieving 41.7% water recovery at 100 psi. However, due to a malfunction caused by a damaged membrane tray and a diverter tray, the results were inconclusive. It was recommended to not process this stream with the VSEP, as the potential for solid mineral recovery is minimal.

The Primary Scrubber Concentration Study processed two effluent samples from the primary scrubber using the VSEP system in batch mode. The runs were stopped when the effluent level became too low to continue without damaging the feed pump. The results were promising, with good flux and potential for continued processing in a different equipment arrangement for full-scale design.

For Primary Scrubber Run 1, the average flux was 62.1 LMH, achieving 95.0% water recovery at 100 psi (6.9 bar). For Run 2, the average flux was 39.7 LMH, achieving 90.9% water recovery at 100 psi. The flux remained steady during Run 1, while Run 2 saw an increase in flux, possibly due to increased pressures or settling solids in the concentrated feed, resulting in reduced resistance to separation.

The Fine Gold Concentration Study processed fine gold stream samples using the VSEP system in batch mode. Run 1 ended when the feed pump had to be stopped to prevent it from running dry, indicating potential for continued processing in a different setup. Run 2 stopped when the limiting flux was reached.

For Run 1, the average flux was 37.1 LMH, achieving 97.5% water recovery at 100 psi (6.9 bar). For Run 2, the average flux was 13.8 LMH, achieving 95% water recovery at 100 psi. Both runs showed decreasing flux trends, with Run 2 showing less decrease. Differences in permeate flux values were due to varying properties of the fine gold streams, such as pH and total suspended solids (TSS) content.

The trial involved processing three waste streams: silver, primary scrubber, and fine gold. The silver stream trials yielded inconclusive results due to a membrane malfunction. It was recommended not processing this stream due to low total suspended solids (TSS) of less than 348 ppm and subsequently low gold recovery potential. However, the primary scrubber stream showed viability for gold recovery via VSEP, with 3.5 and 2.4 times gold concentration for runs 1 and 2, respectively. Similarly, the fine gold stream run 1 concentrated gold up to 11 times, indicating potential for gold recovery using VSEP.

It was highly recommended to do additional trials for a longer period on the primary scrubber and fine gold streams to provide VSEP design data and cleaning information. Additional trials with pH correction may also be considered at the lab scale level to determine if precious metal total dissolved solids (TDS) can be precipitated and recovered by VSEP. If positive results are obtained, the waste streams can be pH corrected before processing in the VSEP plant.

Further testing and exploration of cleaning regimens should be conducted in future pilot testing to determine if a baseline flux has been established, how this affects throughput on feed material, and if other cleaners could be more effective. From the analytical information tested, the permeate had extremely high chlorides, dissolved solids, and conductivity in multiple runs, making it difficult to further treat the permeate for both mineral and water recovery. Recovery from the permeate stream for dissolved gold, silver, copper, and water is not possible with conventional reverse osmosis or advanced techniques such as VSEP with reverse osmosis membranes due to the high TDS content requiring unreasonably high osmotic pressures. Other techniques such as thermal processing, eutectic freeze crystallisation, or advanced softening should be investigated to determine their feasibility.

Based on these and mineral recovery estimates, the plant should be paid off within less than three years. The feasibility of implementing the VSEP unit should consider the performance of the existing filter presses and the quantity of recoverable minerals being disposed of.

These findings from the VSEP trial provide valuable insights into the potential for gold recovery from wastewater at Rand Refinery and highlight the need for further trials and exploration of alternative treatment techniques.

Conclusions

To conclude, the effluent reduction and treatment initiatives at Rand Refinery have achieved notable advancements in decreasing freshwater usage and effluent generation. The successful launch of the granulation water recycle plant and improvements to the silver leach process have significantly lowered effluent volumes and treatment expenses. The Vibratory Shear Enhanced Processing (VSEP) trial has yielded encouraging outcomes for gold recovery from wastewater, but additional trials and the investigation of other treatment methods are suggested.

The water savings from the effluent reduction initiatives are tracked by measuring the volume of effluent transferred to service yard storage facilities using flow meters integrated with SCADA. Since the FY23 introduction of the granulation effluent recycling initiative, effluent has been reduced to 2676 m^3. In FY24, the addition of HCl and $NaClO_3$ to the silver leach process was introduced, further reducing the effluent to 2083 m^3. The cumulative improvements in effluent management between FY23 and FY24 have resulted in a reduction of 590 m^3, achieving savings of R560,500.

These initiatives support Rand Refinery's commitment to ESG compliance, emphasising resource conservation and waste management. The projects not only promote environmental sustainability but also offer staff valuable training in process engineering and effluent management.

In summary, the refinery’s proactive stance on reducing and treating effluent highlights its commitment to sustainable practices and responsibility as a corporate entity. By consistently pursuing innovation and process optimisation, Rand Refinery strives for long-term sustainability and resilience, securing its ongoing success and beneficial influence on both the environment and society.

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