

Exploring the Effects of Seawater Use in Cu-Ni-PGM Ore Flotation against Recycled Mine Water

Malibongwe S. Manono¹, Lisa L. October², Kirsten C. Corin¹

¹Centre for Minerals Research, Department of Chemical Engineering, University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa, malibongwe.manono@uct.ac.za, ORCID 0000-0002-2928-9368

²School of Chemical and Metallurgical Engineering, University of the Witwatersrand, Johannesburg 2017, South Africa

Abstract

This study presents a comparative laboratory investigation of flotation performance using seawater and synthetic recycled mine water for a Merensky Cu–Ni–PGM ore. Batch flotation tests were conducted following standard Centre for Minerals Research protocols and complemented by three-phase froth stability tests. Seawater sourced from two coastal locations was benchmarked against synthetic plant water designed to replicate recycled process water chemistries. Key performance indicators included solids and water recoveries, froth height, froth stability (collapse time), and bubble size, alongside characterisation of water chemistry. Results demonstrate that seawater systems consistently yield higher solids and water recoveries relative to recycled process water.

Keywords: Flotation, mine water, salinity, seawater, water reuse

Introduction

Water availability has emerged as a critical constraint for mining and mineral processing operations globally, particularly in semi-arid regions such as Southern Africa, where platinum group metal (PGM) production is concentrated. Mineral flotation circuits are inherently water-intensive, often comprising up to 85% water by volume, and are therefore highly sensitive to water quality variations (Muzenda 2010). As freshwater resources become increasingly limited, the mining industry is progressively adopting alternative water sources, including recycled process water and seawater, to sustain operations and meet environmental compliance targets (Slatter *et al.*, 2009; Harrison *et al.* 2018). However, the reuse of mine water and the introduction of water of high salinity such as seawater fundamentally alter the chemical environment of flotation systems (Le *et al.* 2020). Elevated ionic strength and the presence of specific ions (e.g., Ca^{2+} , Mg^{2+} , SO_4^{2+}) influence key interfacial phenomena, including collector adsorption, bubble coalescence, froth stability, and entrainment behaviour (Manono *et al.* 2018). In particular, high ionic strength has been shown to

suppress bubble coalescence, resulting in smaller bubble sizes and more stable froths, which can enhance mass pull but may also increase gangue entrainment (Craig *et al.* 1993; Manono *et al.* 2018). These competing effects introduce a critical trade-off between recovery and selectivity in flotation systems operating under saline conditions. While the effects of water chemistry on flotation have been widely studied for base metal systems (Biçak *et al.* 2012), there remains a notable gap in understanding these interactions within the context of Cu–Ni–PGM ores, particularly under seawater conditions (Cisternas and Gálvez 2018). Most existing studies have focused on recycled process water, with limited direct comparison to seawater despite its growing industrial relevance. Furthermore, the distinct ionic composition of seawater, characterised by high concentrations of Na^+ , Cl^- , Mg^{2+} and SO_4^{2+} , introduces additional complexity beyond simple ionic strength effects.

This study therefore aims to provide a comparative assessment of flotation performance in seawater and synthetic recycled mine water for a Merensky Cu–Ni–PGM ore. By systematically evaluating



metallurgical responses and froth stability characteristics under controlled laboratory conditions, this work seeks to advance the understanding of water chemistry as an active metallurgical variable, with implications for water reuse strategies and sustainable processing in PGM operations.

Methods

Ore Preparation

A Cu-Ni-PGM ore from the Merensky reef situated in the Bushveld Igneous Complex (BIC) of South Africa was used for experimentation. The bulk ore sample was crushed, riffled, and then split into 1 kg samples using a rotary splitter. This ensured that the crushed ore had a consistent particle size distribution and composition for each 1 kg bag sample.

Water Quality

Recycled Mine Water

Synthetic plant water of the quality shown in Tab. 1, prepared from salts of analytical grade, was used during milling and flotation experiments. The quality of the synthetic plant water is one that mimics typical recycled mine water in Cu-Ni-PGM ore concentrators in the BIC (Manono *et al.* 2018).

Seawater

Seawater from two different coasts in Cape Town, South Africa were also used during milling and flotation procedures for comparative analysis with synthetic plant

water. Seawater collection was done on the Southern Coast and the Northern Coast relative to the location of the University of Cape Town's Upper Campus. The Southern Coast Seawater (SCSW) was water collected at Rumbly Bay in Millers Point while the Northern Coast Seawater (NCSW) was collected from Silverstroomstrand Resort off the West Coast. The water was collected in five 25 L drums at each location (125 L from each beach). To remove unwanted particles such as leaves and grass, SCSW obtained at Rumbly Bay was left to sediment. The point of collection was relatively clean hence there was no sand obtained and the few dirt particles were dense enough to remain at the bottom of the drum during use of the water. However, the water obtained in the North required filtering using the filter press because the particles present did not sink overnight. Tab. 2 shows data obtained from a microparameter water quality meter. The meter measured different parameters in the SPW, SCSW, NCSW for comparison. In this paper we report the pH, electrical conductivity, pH, and total dissolved solids.

The pH of the three water types was within the range of 7 to 8, SCSW was the most alkaline with the highest pH of 8.29. The results show that the electrical conductivity (EC) of SCSW, with SPW having the lowest electrical conductivity. The EC and TDS of the NCSW were little lower than that of the SCSW, while the EC and TDS of the SPW were the lowest.

Table 1 Ionic Composition of Synthetic Plant Water that Mimics Recycled Mine Water.

Water Type	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Na ⁺ (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	CO ₃ ²⁻ (mg/L)	TDS (mg/L)	Ionic strength (mol/L)
SPW	80	70	153	287	240	176	17	1023	0.0242

Table 2 Summary of Data obtained from a Microparameter Water Quality Meter.

	Unit	SPW	SCSW	NCSW
pH	-	7.61	8.29	7.94
Electrical Conductivity (EC)	µS/cm	3302	31640	21240
Total Dissolved Solids (TDS)	mg/L	1651	15820	10620



Chemical Reagents

Sodium Isobutyl Xanthate (SIBX)

To make a 1% solution of SIBX, one gram of the SIBX was measured on a scale in a weighing dish and added to 100 mL of deionised water and stirred using a spatula. The SIBX used had an activity of 94.4% and it was supplied by AECI Mining Chemicals. This solution was made daily since it decomposes quickly.

Senfroth 200

The frother used in the froth column tests and the flotation procedure is SENFROTH XP 200 provided by AECI Mining Chemicals. The chemical was provided in liquid form already hence no mixing was required; it can be used directly. The molecular weight of SENFROTH XP 200 is 205.40 g/mol and a purity of 98%.

Experimental Matrix

Table 3 shows the experimental matrix that was used. The proposed work had 5 flotation runs that were duplicated to reduce errors, making the runs accumulate to 10 experimental tests in total. The following denotations are used on Tab. 3: SPW = Synthetic Plant Water, SCSW = South Coast Seawater, NCSW = North Coast Seawater, M = Milling, F = Flotation. An experimental condition showing SPW-SPW implies that the water used for milling was SPW and the water used during flotation was SPW.

Batch Milling and Flotation Procedure

A 1 kg sample of the crushed ore was poured into a rod mill and 500 mL of either SPW or seawater was added to the mill depending on the experimental run being conducted to produce a slurry of 66% solids. A syringe was then used to draw 15 mL of the SIBX which was then poured into the ore and water to mix inside the mill. The mill was securely closed and allowed to run for 21 minutes as this was

determined as the required time to obtain a grind of 60% passing 75 µm. The milled slurry was then transferred to a 3 L UCT Barker Flotation cell where the 3 L volume was made up by the required water type (SPW, SCSW or NCSW). This produces a slurry of 35% solids. Following the standard UCT flotation procedure described in (Wiese *et al.* 2005), The impeller was then switched on to a constant speed of 1200 rpm, and this was followed by extracting 50 mL feed sample (with no reagents except the collector added during milling). At t = 0 min, the frother was then added and allowed to condition for a minute. After the frother conditioning time, at t = 1 min the air supply is added and maintained at a flowrate of 7 L/min for all the tests. The froth height was maintained at the 2 cm mark by using top up with of the required water at regular time intervals. The concentrates were then scraped in 15 s intervals with four concentrates collected. The air supply was then turned off, and two 50 mL tailing samples were taken. The bulk tails, small tails samples, feed and concentrates filtered and left overnight in an oven to dry. Samples were thereafter weighed and analysed for Cu and Ni using a handheld XRF analyser.

Results and Discussion

Solids and Water Recoveries

Fig. 1 shows a comparison of the trends on solids and water recoveries for the selected ore milled and floated in various water qualities with the baseline condition being milling in synthetic plant water and flotation in synthetic plant water (SPW-SPW).

It can be seen from Figure 1 that the milling in SPW and flotation in SCSW resulted in an increase in solids and water recoveries compared to the baseline condition of SPW-SPW. Milling in SPW and flotation in NCSW resulted in an even greater increase in solids and water recoveries.

Table 3 Experimental Matrix Followed during the Study.

Experiment	SPW-SPW		SPW-SCSW		SPW-NCSW		SCSW-SCSW		NCSW-NCSW	
	M	F	M	F	M	F	M	F	M	F
Water Added	SPW	SPW	SPW	SCSW	SPW	NCSW	SCSW	SCSW	NCSW	NCSW

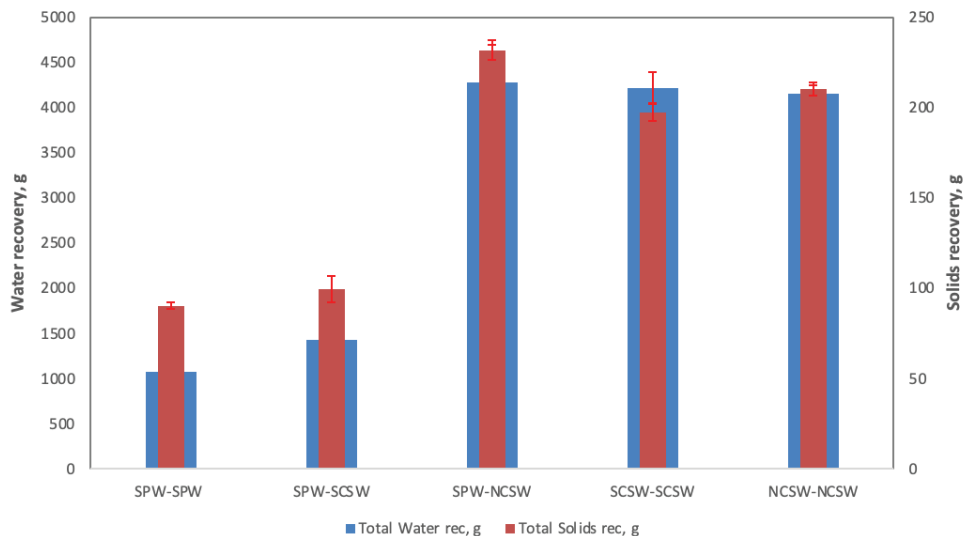


Figure 1 Solids and water recoveries in synthetic plant water.

Copper Recoveries and Grades

Fig. 2 shows a comparison of the flotation of copper recoveries and grades for the selected ore milled and floated in various water qualities.

It can be seen from Fig. 2 that copper recoveries follow a similar trend to that observed for solids and water recoveries,

increasing as the system is changed from SPW-SPW to seawater conditions. The baseline SPW-SPW condition exhibits the lowest copper recovery, while the introduction of seawater during flotation (SPW-SCSW and SPW-NCSW) results in improved recoveries. In contrast, copper grades show an opposing trend, with higher recoveries associated with a reduction in grade.

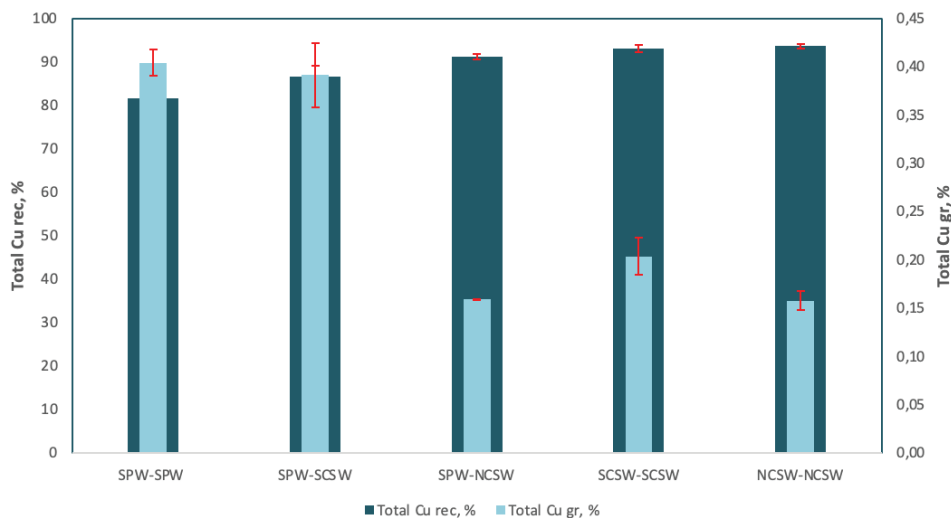


Figure 2 Cu recoveries and grades in synthetic plant water and seawater.

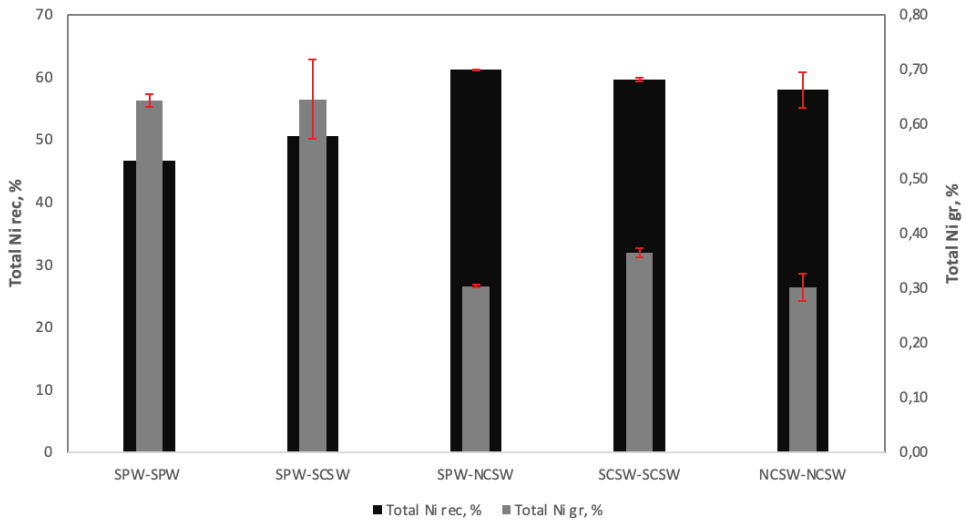


Figure 3 Ni recoveries and grades in synthetic plant water and seawater.

Nickel Recoveries and Grades

Fig. 3 shows a comparison of the flotation of copper recoveries and grades for the selected ore milled and floated in various water qualities.

Fig. 3 shows that nickel recoveries exhibit trends consistent with those observed for copper and overall solids recovery. Recoveries increase progressively from SPW-SPW through to seawater-dominated systems,

with SPW-NCSW, SCSW-SCSW and NCSW-NCSW conditions showing the highest nickel recoveries. Similar to copper, nickel grades display an inverse relationship with recovery

Froth Properties

Fig. 4 shows the froth height and collapse time in SPW, SCSW and NCSW.

Fig. 4 shows that both froth height and froth collapse time increase significantly with

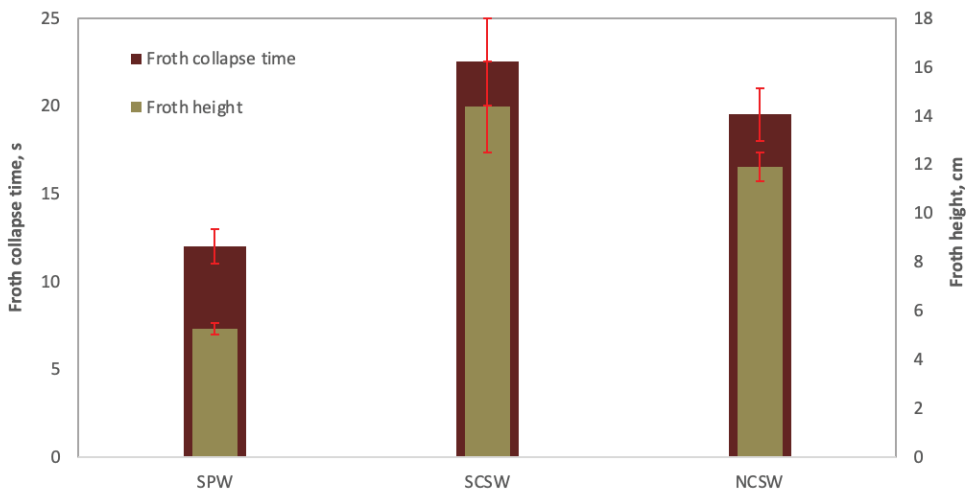


Figure 4 Froth height and froth collapse time in SPW, SCSW and NCSW.

increasing salinity of the water. The lowest froth height and fastest collapse are observed under SPW conditions, indicating a relatively unstable froth. In contrast, seawater systems (SCSW and NCSW) exhibit higher froth heights and longer collapse times, reflecting enhanced froth stability.

Fig. 5 shows the images of the froth phase during the flotation with the different water types. The images were captured at the beginning of the flotation process, during the collection of the first concentration.

Fig. 5 shows a clear variation in froth bubble size and distribution across the different water types. The SPW system is characterised by larger and less uniform bubbles. In contrast, seawater systems produce smaller and more uniformly distributed bubbles, with NCSW showing the finest and most homogeneous bubble structure.

Linking Flotation Performance with Froth Properties and Water Quality

The observed increase in solids, water, and mineral recoveries under seawater conditions correlates directly with the elevated electrical conductivity and total dissolved solids reported in Table 2, which reflect significantly higher ionic strength relative to SPW. Increased ionic strength is well known to suppress bubble coalescence, resulting in smaller, more stable bubbles and enhanced froth stability (Craig *et al.* 1993; Manono *et al.* 2013). This is consistent with the

higher froth heights, longer collapse times, and finer bubble size distributions observed in Fig. 4 and 5. The more persistent froth phase promotes increased water recovery and entrainment, explaining the higher mass pull and corresponding increase in mineral recoveries, albeit at the expense of grade. The intermediate behaviour observed for recycled process water (SPW) reflects its lower conductivity and ionic strength, resulting in less stable froths and reduced entrainment. Furthermore, the presence of divalent ions such as Ca^{2+} and Mg^{2+} in both seawater and recycled water is known to influence interfacial properties and froth stability, reinforcing these trends (Farrokhpay and Zanin 2012; Manono *et al.* 2018). These results demonstrate that water chemistry, as captured by conductivity and TDS, exerts significant control on froth behaviour and, consequently, flotation performance.

Conclusions

The results indicate that seawater consistently produced higher solids and water recoveries than synthetic process water, attributed primarily to its substantially higher ionic strength. Enhanced froth stability, characterised by increased froth heights and longer collapse times, was observed in seawater systems, reflecting reduced bubble coalescence and smaller bubble sizes. Recycled process water showed intermediate behaviour, with flotation response influenced

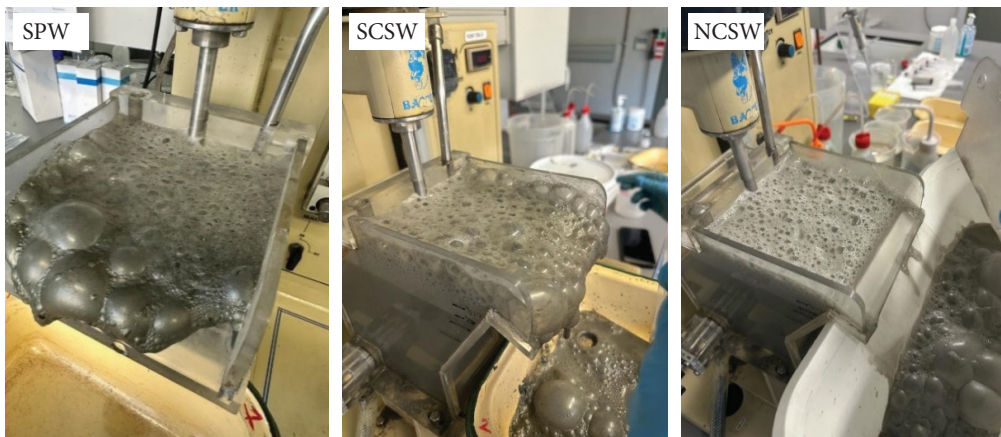


Figure 5 Froth Bubble size comparison during flotation in SPW, SCSW and NCSW.



by divalent ions such as Ca^{2+} and Mg^{2+} . While higher ionic strength increased mass pull, it also increased the potential for gangue entrainment, highlighting trade-offs between recovery and selectivity. The findings demonstrate that water quality should be treated as an active metallurgical variable rather than a passive process input. This work provides evidence to support informed decision-making around seawater use, mine water recycling, and closed-loop water circuits in PGM operations as seawater has not been researched in the context of PGM ores. The study further contributes to the broader understanding of how mine-affected water chemistries influence processing performance, supporting sustainable water management strategies under increasing water scarcity.

Acknowledgements

The author would like to acknowledge the University of Cape Town for supporting this work. Theresa Chibaya and Kidada Mhishi are acknowledged for conducting the test work as part of their final year project towards the degree of BSc(Eng) in Chemical Engineering at the University of Cape Town.

References

- Biçak Ö, Ekmekçi Z, Can M, Öztürk Y (2012) The effect of water chemistry on froth stability and surface chemistry of the flotation of a Cu-Zn sulfide ore. *Int J Miner Process* 102–103:32–37. <https://doi.org/10.1016/j.minpro.2011.09.005>
- Cisternas LA, Gálvez ED (2018) The use of seawater in mining. *Mineral Processing and Extractive Metallurgy Review* 39:18–33. <https://doi.org/10.1080/08827508.2017.1389729>
- Corin KC, Reddy A, Miyen L, et al (2011) The effect of ionic strength of plant water on valuable mineral and gangue recovery in a platinum bearing ore from the Merensky reef. *Miner Eng* 24:131–137. <https://doi.org/10.1016/j.mineng.2010.10.015>
- Craig VSJ, Ninham BW, Pashley RM (1993) The effect of electrolytes on bubble coalescence in water. *J Phys Chem* 97:10192–10197. <https://doi.org/10.1021/j100141a047>
- Farrokhpay S, Zanin M (2012) An investigation into the effect of water quality on froth stability. *Advanced Powder Technology* 23:493–497. <https://doi.org/10.1016/j.apt.2012.04.012>
- Harrison STL, Slatter-christie K, Broadhurst J (2018) Integrating competing water needs of mining and mineral processing with the environment, community and economic activity in a mining-dominated catchment
- Le T, Schreithofer N, Dahl O (2020) Dissolution Test Protocol for Estimating Water Quality Changes in Minerals Processing Plants Operating With Closed Water Circulation. *Minerals* 10:653. <https://doi.org/10.3390/min10080653>
- Manono M, Corin K, Wiese J (2018) Water quality effects on a sulfidic PGM ore : Implications for froth stability and gangue management. 54:1253–1265. <https://doi.org/10.5277/ppmp18181>
- Manono MS, Corin KC, Wiese JG (2019) To Recycle or Not ? A Bench Scale Simulation of Water Recirculation in Sulfidic Cu-Ni Ore Flotation. In: Khayrulina, E.; Wolkersdorfer, Ch.; Polyakova, S.; Bogush A (ed) *Mine Water – Technological and Ecological Challenges*. International Mine Water Association, pp 225–231
- Manono MS, Corin KC, Wiese JG (2013) The effect of ionic strength of plant water on foam stability: A 2-phase flotation study. *Miner Eng* 40:. <https://doi.org/10.1016/j.mineng.2012.09.009>
- Muzenda, E (2010) An Investigation into the Effect of Water Quality on Flotation Performance. *World Academy of Science, Engineering and Technology International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering* 4:562–566
- Slatter, K.A.; Plint, N.D.; Cole, M.; Dilsook, V.; De Vaux, D.; Palm, N.; Oostendorp B (2009) *Water Management in Anglo Platinum Process Operations: Effects of Water Quality on Process Operations*. International Mine Water Conference, Pretoria, South Africa, 19th – 23rd October 2009 Proceedings ISBN Number: 978-0-9802623-5-3 46–55
- Wiese J, Harris P, Bradshaw D (2005) The influence of the reagent suite on the flotation of ores from the Merensky reef. *Miner Eng* 18:189–198. <https://doi.org/10.1016/j.mineng.2004.09.013>