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Optimization of the Jameson Cell Performance through Dilution Cleaning Tests

Benedict Ogalabyoshi Ndagano[1], **Rodrigue Ciband Kaut'a Wang**[2], **Clarisse Muntu Wa Mwami**[1], **Meschac Amani Mugaruka**[1], **Binkat Aganze Katembera**[1], **Alphonse Murhambo Kaningu**[1]

[1]School of Mines, Université Officielle de Bukavu, Bukavu, Democratic Republic of the Congo
[2]Ivanhoe, Kamoa Copper SA, Kolwezi, Democratic Republic of the Congo
Email: ben.ogalabyoshi@gmail.com

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Abstract

This study investigates the optimization of Jameson Cell performance at the Kamoa-Kakula concentrator through dilution cleaning tests. The experiments aimed to evaluate the effects of frothers (Hydrofroth 5008 and Flotanol) and a collector-frother combination (Sodium Isobutyl Xanthate with Senfroth 522) on flotation efficiency. Bench-scale flotation tests were carried out on feed samples from Jameson Cells N˚1 and N˚2 under controlled laboratory conditions, with systematic dilution cleaning across three stages. Results showed that Hydrofroth 5008 moderately increased copper recovery but at the expense of concentrate grade due to enhanced gangue entrainment. Conversely, Flotanol significantly improved both grade and recovery at optimized dosages, although excessive addition decreased selectivity. The combined use of Sodium Isobutyl Xanthate and Senfroth 522 yielded the most notable improvements, achieving copper recoveries above 95% with concentrate grades up to 65% Cu, while reducing copper losses in tailings. These findings highlight the importance of reagent selection and dosage control in balancing recovery and concentrate quality, ultimately providing insights for optimizing Jameson Cell operations in large-scale copper concentrators.

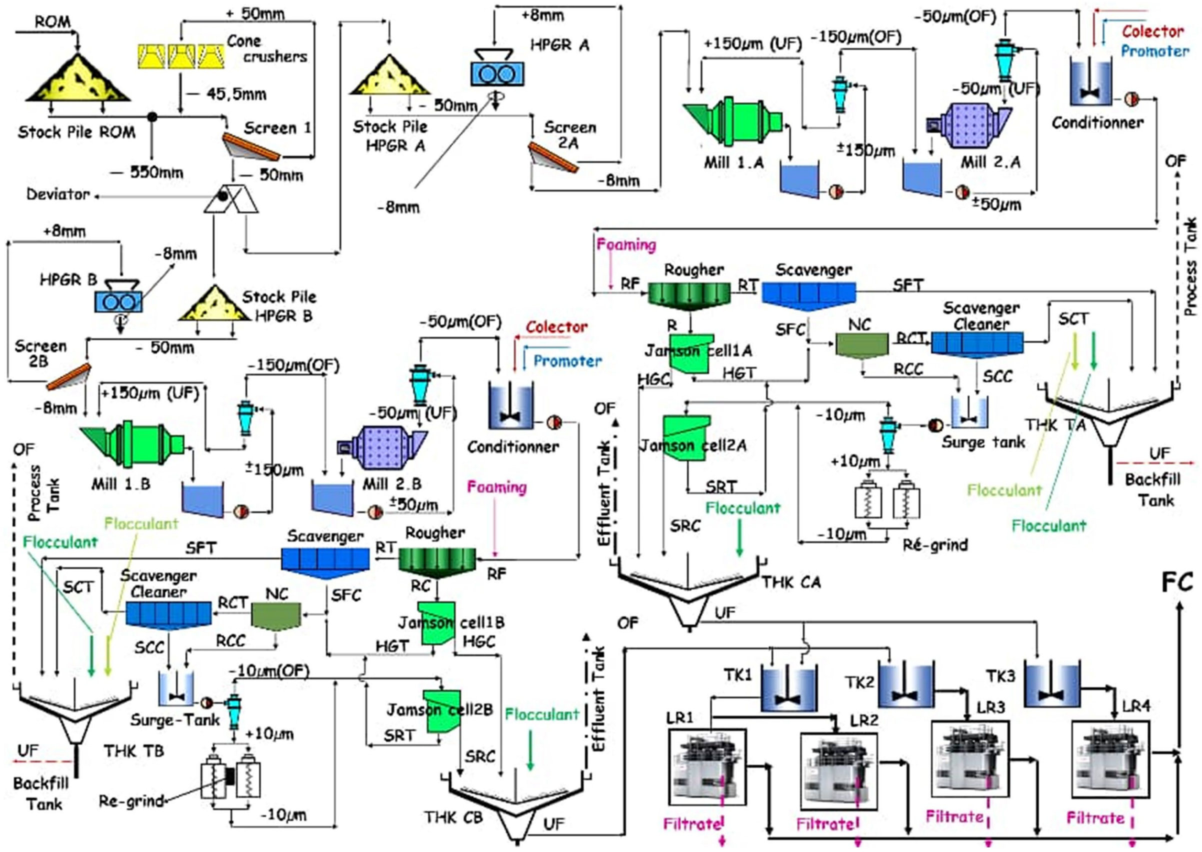
Keywords

Jameson Cell, Flotation Performance, Dilution and Cleaning Tests, Copper Recovery, Concentrate Grade, Frothers, and Collectors

1. Introduction

Since their commercial introduction in 1989, Jameson Cells have become increasingly common in the mineral and coal industries [1]. Jointly developed by Mount Isa Mines and Professor G.J. Jameson in 1986, the Jameson Cell is now used in over 225 installations. It is different from traditional flotation columns and mechanical cells due to differences in residence time and aeration [1]-[3]. They are like pneumatic flotation cells, but do not require compressed air [3] [4]. The Jameson Cell design allows for high production rates within a significantly smaller physical footprint, produces high-grade concentrates, and exhibits rapid flotation kinetics [3] [5]-[7]. The absence of internal moving parts (other than the feed pump) contributes to lower maintenance needs and stable operation, further supported by the internal tailings recycle system [2] [4] [7]. The overall efficiency of froth flotation is quantitatively assessed using various performance indicators, including the Ratio of Concentration, Percentage Metal Recovery, Percentage Weight Recovery, and visually through Grade-Recovery Curves [8]-[10]. For fine particle systems, an important factor in achieving high recovery is the method of bubble generation and dispersion [1] [11] [12]. While reagent chemistry is always important for inducing hydrophobicity, the physical design of the flotation cell, especially its ability to generate and disperse fine bubbles, plays a key role in enhancing collision and attachment probabilities [7] [12]. The increased bubble surface area provided by fine bubbles fundamentally boosts collision frequency and kinetics, leading to faster flotation rates and higher recovery for fine particles [3] [12]. This underscores that, for challenging fine-grained ores, the cell's design, particularly its capacity for fine bubble generation, becomes a primary factor in metallurgical efficiency, explaining the widespread adoption of the Jameson Cell for fine coal and complex sulfide ores [5] [13]. Despite the inherent selectivity of the flotation process in recovering valuable minerals, a common operational challenge is the mechanical entrainment of unwanted gangue particles into the froth product. This phenomenon is especially common with fine gangue particles (typically less than 10 μm) that are carried into the froth along with interstitial water, rather than through selective hydrophobic attachment [14] [15]. The presence of these entrained gangue particles contaminates the concentrate, reducing its purity and overall grade [15]. To address this issue, dilution cleaning, primarily through froth washing, is an essential technique. Its main goal is to reduce the mechanical entrainment of gangue minerals, which directly improves concentrate grade and enhances separation selectivity [8] [15]. The froth washing process involves strategically spraying clean wash water onto the surface of the froth layer [8].

Figure 1 presents the simplified flowsheet of the Kakula concentrator in the Democratic Republic of Congo. Jameson cells were chosen due to their ability to reduce entrainment with a froth wash feature and their operational stability, achieved by recycling a portion of tailings back into the feed. The Kakula deposit is characterized by copper present in sulfides and oxides, with the deposit's mineralogy mainly consisting of chalcocite and bornite, resulting in a high-grade ore with favorable metallurgical properties. This composition necessitated adjustments to the ore processing flowsheet. As shown in **Figure 1**, the Kakula concentrator utilizes Jameson cells for high-grade cleaner (Jameson N˚1: 72% Cu at 81% stage recovery) and scavenger recleaner (Jameson N˚2: 40.7% Cu at 71.5% stage recovery) duties. The Kamoa Jameson Cells have been installed and commissioned to clean concentrate from roughers and scavenger cleaners after regrinding, achieving good stage recovery and a high-quality concentrate (with more copper and less silica). While performance is currently meeting targets for grade, recovery, and stability, there is potential for further optimization.



ROM: Run of Mine, HPGR: High-Pressure Grinding Rolls, Mill: Milling, RF: Rougher Feed, SFT: Scavenger Final Tails, SCT: Scavenger Concentrate Tails, TK: Thank, LR: Larox, R: Rougher, RT: Rougher Tails, SFC: Scavenger Final Concentrate, SCT: Scavenger Flotation Tails, SRC: Scavenger Recleaner Concentrate, SRT: Scavenger Recleaner Tails, THT: Thickener Tails, THC: Thickener Concentrate, OF: Overflow, UF: Under Flow, HGC: High-Grade Concentrate, HGT: High-Grade Tails, NC: New Cleaner, SCC: Scavenger Cleaner Concentrate, SCT: Scavenger Cleaner Tails, FC: Final Concentrate.

Figure 1. Simplified flowsheet of the Kakula concentrator highlighting the application of Jameson Cells for high-grade cleaning and scavenger recleaning.

The overall goal of this study is to optimize the Jameson cells at the Kamoa Kakula site by conducting a dilution test. The specific objectives are, first, to examine how adding different dosages of frothers (HYDROFROTH 5008 and FLOTANOL) affects the performance of the Jameson cells. The supplier recommends using a frother to ensure process stability, but plant operators have reservations about its effectiveness in meeting operational KPIs (grade and mass pull). Second, to evaluate the impact of adding a collector (SIBX) and a frother (SNF522) on Jameson cell performance. Third, to compare the results of the dilution tests with those obtained without reagents (collector/frother).

2. Materials and Methods

2.1. Materials

The dilution cleaning tests were conducted using fresh samples from the Jameson Cell feed streams, including rougher concentrate (Jameson N˚1) and scavenger cleaner concentrate (Jameson N˚2) from the Kakula concentrator. During the flotation tests, Sodium Isobutyl Xanthate (SIBX) was used as the collector (product of Axis House), Hydrofroth 5008 (HDF), Senfroth 522 (SNF522), Flotanol, and Methyl Isobutyl Carbinol (MIBC) were employed as frothers. The water used in the experiments originated from the Kakula wastewater treatment plant. The chemical characterization of the sample was carried out for various metals using X-ray Fluorescence Spectroscopy (Niton^{TM} XL5 Plus Handheld, Japan).

2.2. Methods

The flotation tests in this research were conducted on fresh samples obtained shortly after production from grinding, regrinding, or the previous flotation stage. The goal was to collect enough samples of fresh feed from Jameson cells (1 and 2) to perform bench-scale flotation tests, ensuring that the samples came from the Jameson cells directly and not from the downspout, which contains recirculation reject. Three tests were performed. When collecting samples for the flotation tests, also take spot samples of the Jameson cell's fresh feed, concentrate, and reject streams, and send these samples for analysis.

The test procedure involved: 1) sampling from Jameson Cell feed, concentrate, and tail streams; 2) bench-scale flotation using a Kamoa Altso flotation lab machine; 3) applying dilution cleaning flotation across three stages; 4) assessing the effects of frother (HF5008 & Flotanol) and collector (SIBX & SNF522) on flotation performance; 5) analyzing Cu and SiO_2 grades and recoveries.

2.2.1. Dilution Test Procedure

The cleaning test procedure involved floating the sample to a single concentrate in a flotation cell following the standard laboratory flotation method for the specific flotation stage (e.g., the rougher/purifier or cleaner). The goal is to operate the first flotation stage at the typical Jameson feed solids percentage and keep solids below 10% for the subsequent two stages. Reagent conditions should mimic those added to the Jameson cell under operating plant conditions. Since the flotation of the second and third stages should occur at a low solids density, a foaming agent was added to both stages to ensure small bubbles and stable foam were produced. As the foaming agent is water-soluble, a large volume of process water solution was prepared beforehand to maintain the proper concentration of the foaming agent when water was introduced throughout the three stages of the test. For MIBC, 12 to 20 ppm were added to ensure the necessary concentration of the foaming agent throughout the test.

Before the flotation tests, process water was added to fill the flotation cell to the required level, then the agitator was started at a speed appropriate for the cell size.

The foaming agent was dosed into the cell to achieve the desired concentration, and the other necessary reagents were added to the test as the fresh feed sample was collected before adding reagents to the concentrator. For each test, a stopwatch, a foam scraper, and a bottle of wash water were required. A tray or collection dish was placed under the cell rim to collect the concentrate. The stopwatch was started, and flotation was initiated by adjusting the air flow to an appropriate level. Throughout the tests, water was added to maintain the level in the cell. The flotation times used in the Jameson Cell laboratory dilution cleaning procedure are based on the experimentally determined time T_1, defined as the duration required in the first cleaning stage until the froth is depleted of mineralized bubbles, referred to as a sterile froth. During the first flotation test, the concentrate is collected in a vessel for a period (T1) until mineralization is complete and the bubbles are sterile. This marks the "1st cleaner." The residues left in the flotation cell after each cleaning stage are filtered, and the cell is cleaned before preparing for the next washing stage.

The second wash involved returning the concentrate collected in the first wash to the flotation cell and then adding process water containing only pH modifiers and foaming agents to fill the flotation cell to the required level for the flotation test.

Following the previously used method, the concentrate was collected in a collection vessel for a duration expressed by Equation (1). The 7/8 factor is an empirical ratio developed from Jameson Cell studies [15]. They simulate the progressive reduction in flotation kinetics across cleaning stages. The second stage slightly reduced the time, because the feed is already upgraded, with fewer floatable particles.

$$T_2 = \frac{7}{8} \times T_1 \text{ min} \tag{1}$$

Recording the collection rate at this stage was crucial for determining the timing of the third stage (Stage 3). In the third stage (third wash), the concentrate obtained from the second test (2nd wash concentrate) was floated by adding process water, pH modifiers, and a foaming agent to the cell, thereby reaching the necessary level for the flotation test. During this stage, four concentrates were collected over a period expressed by Equation (2). The third stage (T_3) further reduced the time, reflecting a very low remaining floatable mass and the need to prevent excessive gangue carryover.

$$T_3 = \frac{5}{8} \times T_1 \text{ min} \tag{2}$$

This means the flotation time should be divided to obtain four concentrate samples of roughly similar mass. Therefore, the initial concentrate sample was collected over a short duration, which gradually lengthens as the mass decreases throughout the process. This produces the "third cleaning concentrate increments," or concentrates 1, 2, 3, and 4. Times should be adjusted according to the cell being simulated and the kinetics of the minerals present to ensure that data points are obtained along the yield/hold curve. The residues (3rd wash reject) and four concentrate samples from each tray for this stage were separately filtered.

In general, seven samples were obtained following various tests, as shown in Figure 2 (Conc 1, Conc 2, Conc 3, Conc 4, Tail 3, Tail 2, Tail 1). Each sample was dried, weighed, and prepared for chemical analysis to determine the presence of relevant elements, including copper (Cu) and silica (SiO_2).

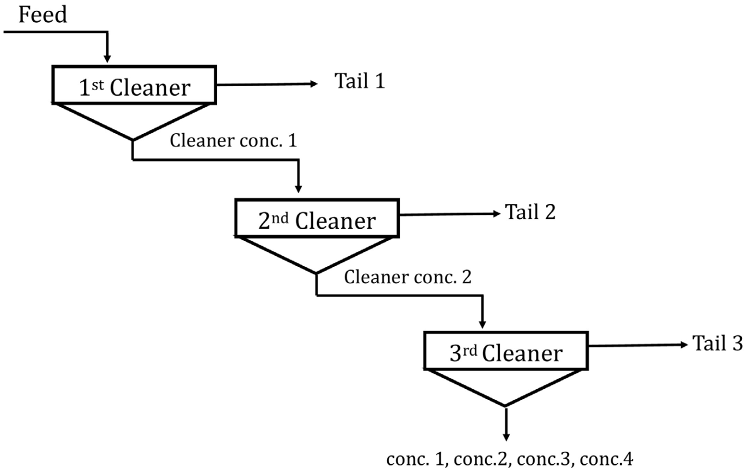


Figure 2. Laboratory flowsheet for the dilution cleaning test procedure, illustrating sampling and three-stage flotation cleaning.

2.2.2. Test Conditions

Every bench test was conducted under operational conditions as described in Table 1.

Table 1. Test conditions parameters.

Parameters	Unit	Values
Pulp density	g/l	1.23
Pulp volume	l	2.8
Solid density	g/cm^3	3.5
Solid percentage	%	26.18%
Impeller speed	rpm	500
pH	-	8.33

Table 2 summarizes the experimental plan designed to evaluate Jameson Cell's performance under dilution cleaning conditions. Two series of tests were conducted. In Series 1, the goal was to assess how the addition of frothers (Flotanol and HDF5008 at different dosages) affects flotation performance without the use of collectors or promoters. In Series 2, the combined effect of collectors (SIBX) with frother (SNF522) was examined. The tests were performed independently on two Jameson Cells (Cell No. 1 and Cell No. 2), using the same reagent schemes for both units. To ensure reproducibility, each test was duplicated. Blank tests (without reagents) were also included to establish baseline performance. This systematic plan enables isolating the influence of each reagent type and their interactions on the cleaning efficiency of the Jameson Cell.

Table 2. Dilution cleaning test plan applied to Jameson Cells.

Test Plan	Collector (g/t)	Frother (g/t)	Jameson Cell No. 1	Jameson Cell No. 2
Blank Test	–	–	No reagents added	No reagents added
Series 1—Impact of Frother				
Test N˚1	–	HF5008 (15)	Applied	Applied
Test N˚2	–	HF5008 (30)	Applied	Applied
Test N˚3	–	Flotanol (15)	Applied	Applied
Test N˚4	–	Flotanol (30)	Applied	Applied
Series 2—Impact of Collector and Frother				
Test N˚1	SIBX (20)	SNF522 (10)	Applied	Applied
Test N˚2	SIBX (40)	SNF522 (10)	Applied	Applied
Test N˚3	SIBX (60)	SNF522 (10)	Applied	Applied

3. Results and Discussion

The dilution cleaning tests conducted on Jameson Cells N˚1 and N˚2 revealed clear trends regarding the impact of frother and collector addition on flotation performance.

3.1. XRF Chemical Analysis of Flotation Products from Jameson Cells

Table 3 presents the chemical composition of the flotation products, which were determined by X-ray fluorescence (XRF). Spot samples were collected from the Rougher Concentrate (RC), High-Grade Concentrate (HGC), and High-Grade Tailings (HGT) for Jameson Cell No. 1, as well as from the Scavenger Concentrate (SCC), Scavenger Recleaner Concentrate (SRC), and Scavenger Tailings (SRT) for Jameson Cell No. 2.

Table 3. Chemical composition of the flotation products from the Kakula Concentrator.

Stream (Spot Sample)	% Cu	% SiO_2
Jameson Cell N˚1		
RC (Rougher Concentrate)	38.7	37.7
HGC (High-Grade Concentrate)	59.9	7.86
HGT (High-Grade Tailings)	29.6	45.8
Stage Recovery (%)	46.5	–
Upgrading Ratio	1.5	–

Continued

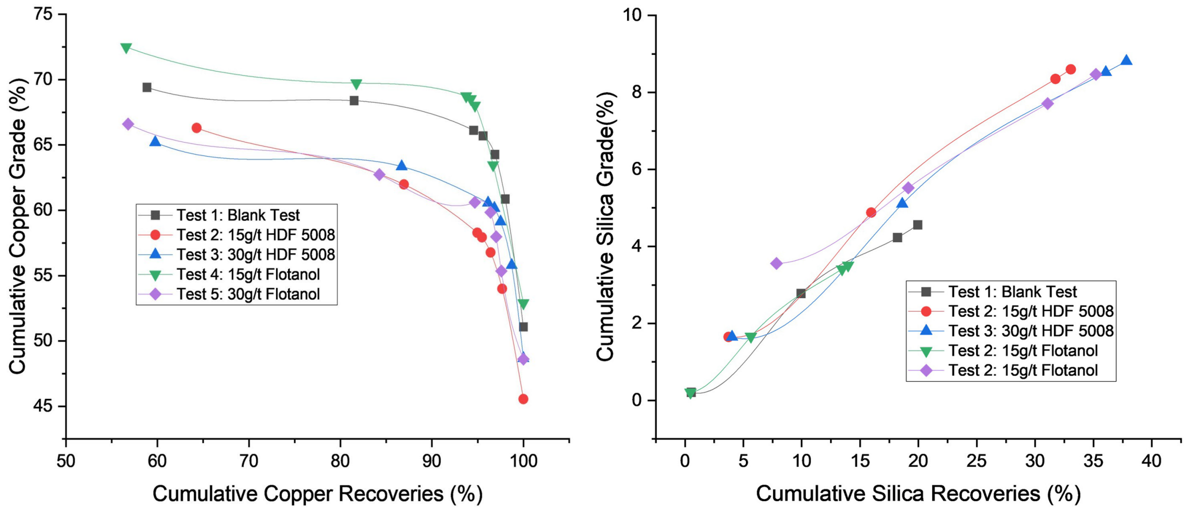
Jameson Cell N˚2		
SCC (Scavenger Concentrate)	22.0	47.4
SRC (Scavenger Recleaner Concentrate)	49.9	13.9
SRT (Scavenger Tailings)	12.5	58.5
Stage Recovery (%)	57.6	–
Upgrading Ratio	2.3	–

For Jameson Cell N˚1, the stage recovery was 46.5%, with an upgrading ratio of 1.5. The silica content in HGC was very low (7.86% SiO_2), whereas copper losses in the tailings were significant (29.6% Cu).

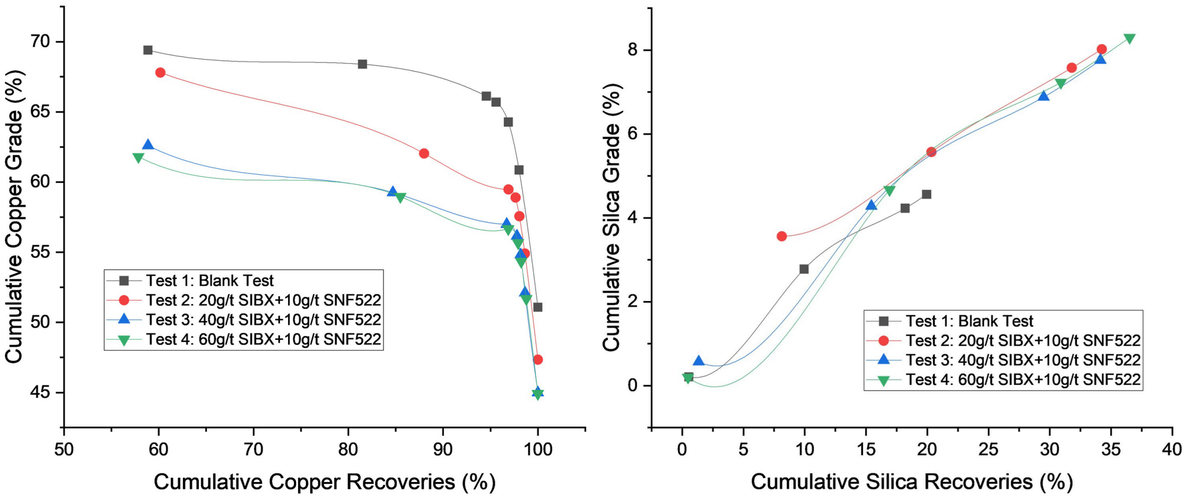
For Jameson Cell N˚2, the stage recovery increased to 57.6% with an upgrading ratio of 2.3. The silica content in SRC remained moderate (13.9% SiO_2), but copper in the tailings was still relatively high (12.5% Cu). The regrind mill was operating without bypass (0%).

3.2. Performance of Jameson Cell N˚1

Figure 3 shows the copper flotation performance with various combinations of collectors and frothers, highlighting the relationship between concentrate grade, copper recovery, and silica recovery. In the blank test (without reagents), Jameson Cell N˚1 achieved a high copper recovery (95.6%) with a concentrate grade of 65.7% Cu and 4.6% SiO_2 (Figure 3(a) and Figure 3(b)). However, tails still contained 24.6% Cu, highlighting potential recovery losses. When frothers were introduced, noticeable differences in performance were observed. With Hydrofroth 5008 (HDF5008), copper recovery improved slightly to as high as 96.8%, while the copper content in the tailings decreased to around 17% - 19% (Figure 3(a) and Figure 3(b)). However, this gain in recovery came at the cost of concentrate quality.



(a) (b)



(c) (d)

Figure 3. Performance of Jameson Cell N˚1 under different conditions: (a) (b) Comparison between blank test and adding frother (HDF and Flotanol), using RC sample; (c) (d) Comparison between blank test and adding frother and collector tests using RC sample.

The concentrate grades fell to 57% - 60% Cu, with silica content rising to 8% - 9%. These results suggest that higher dosages of HDF5008 increased mass pull but also caused gangue minerals to be entrained. Conversely, Flotanol showed a more positive response at lower doses. At 15 g/t, both copper grade (68.5% Cu) and recovery (94.3%) increased, with only a slight decrease in copper in the tailings. When the dosage was raised, recovery continued to improve to 96.4%, but concentrate grades dropped to about 60% Cu, and silica content increased to 8.5% (Figure 3(c) and Figure 3(d)). This indicates that while Flotanol can boost recovery efficiency, excessive addition similarly reduces concentrate selectivity.

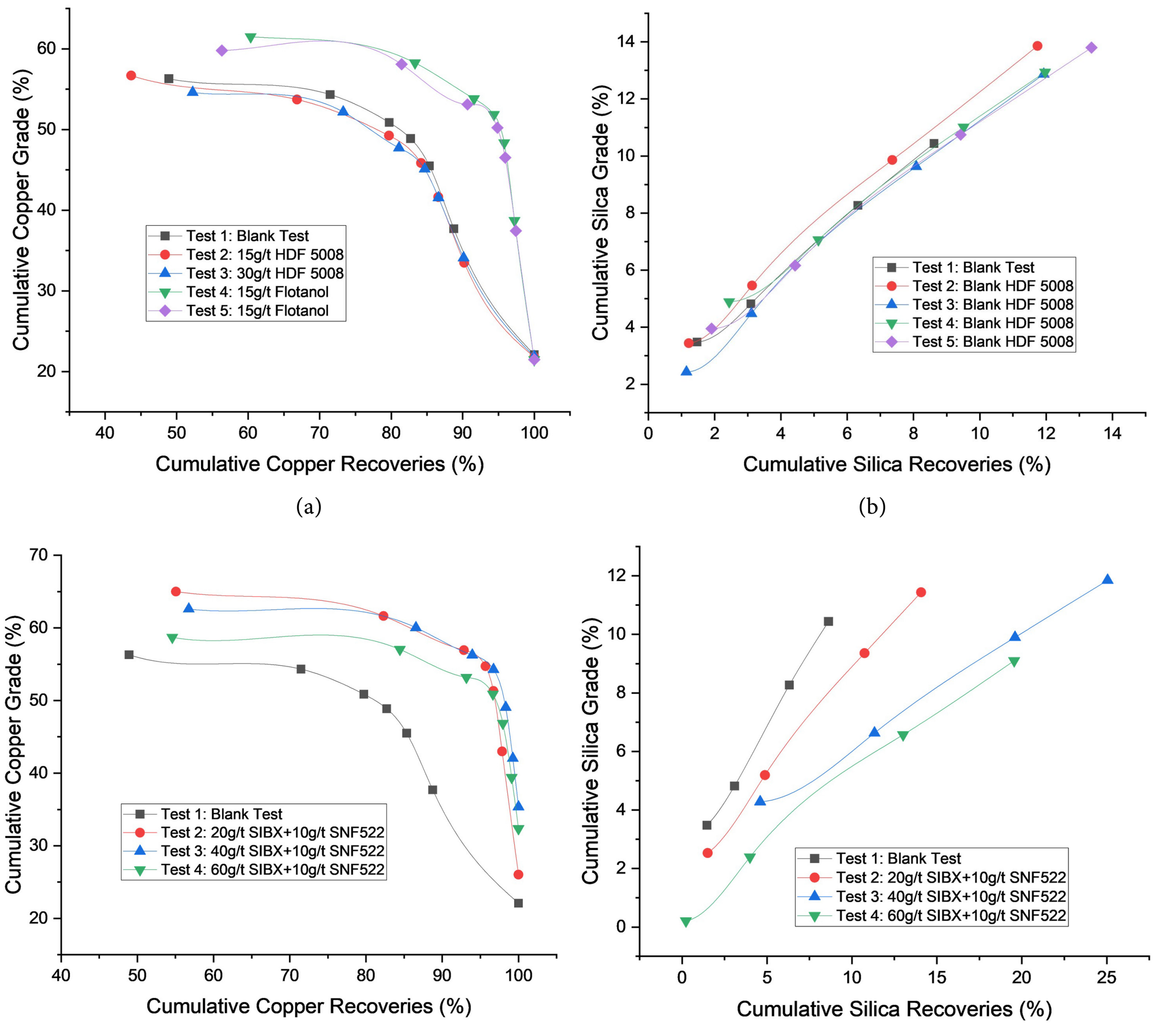
Adding the collector (SIBX) and the frother (SNF522) further improved performance. Low additions (20 g/t SIBX + 10 g/t SF522) significantly reduced tail Cu from 24.6% to 8.8% and increased overall recovery to 97.6%. However, higher collector doses (40 - 60 g/t) continued to lower tail Cu (~6% - 8%) but also decreased concentrate grades (to around 55% - 56% Cu), indicating excessive mass pull.

3.3. Performance of Jameson Cell N˚2

Figure 4 shows the copper flotation performance with various combinations of collectors and frothers, highlighting the relationship between concentrate grade, copper recovery, and silica recovery.

In the blank lab test, recovery improved to 82.7%, but the concentrate grade dropped to 48.9% Cu with 10.4% SiO_2, indicating higher dilution at the laboratory scale. Adding frothers had different effects on Jameson Cell performance. HF5008 slightly increased copper recovery to about 85%, but it did not improve concentrate quality. In contrast, Flotanol was more effective by boosting both recovery and grade. With its use, concentrate grades increased to roughly 52% Cu, and recovery rose to about 95%, while copper in the tailings dropped significantly to 6.3%.

The use of a collector (SIBX) combined with a frother (SNF522) produced even stronger improvements. At low dosages (20 g/t SIBX + 10 g/t SNF522), concentrate grades increased sharply to 65% Cu, recovery rose to 95.7%, and the copper content in the tailings dropped to ~7.6%. Increasing the dosage to 40 - 60 g/t further boosted recovery to ~96% - 97%, but concentrate grades fell to ~59% - 61% Cu, reflecting excessive mass pull. This trend was consistent with results from Cell N˚1, where overdosing reduced selectivity despite higher recovery.



(a) (b)

(c) (d)

Figure 4. Performance of Jameson Cell N˚2: (a) (b) Comparison between blank test and adding frother (HDF and Flotanol), using SCC sample; (c) (d) Comparison between blank test and adding frother and collector tests using SCC sample.

3.4. General Discussions

Across both cells, reagent addition consistently involved a trade-off between grade and recovery. Frothers increased mass pull and recovery but risked diluting concentrate quality due to higher silica entrainment. This trend aligns with the findings of Niedoba *et al.* (2021), who demonstrated through multidimensional optimization of a Jameson C'esticio that excessive dosages of frother or collector increase gangue entrainment, while moderate levels strike a better balance between grade and recovery. Collectors, when used at low dosage with a frother, provided the optimal balance, reducing copper losses in tails while maintaining acceptable concentrate grades. However, overdosing reduced selectivity and unnecessarily increased reagent consumption, raising operational costs. This aligns with the review by Zhang *et al.* (2025), which emphasizes the importance of molecularly designed collectors and frothers [16], aided by machine learning, in maintaining selectivity while reducing reagent use.

These findings confirm that laboratory dilution cleaning tests are effective diagnostic tools for optimizing Jameson Cell performance. The results show that modest reagent dosages, especially Flotanol and low levels of SIBX + SNF522, can be strategically utilized in plant operations to enhance copper recovery while maintaining a controlled concentrate grade. Additionally, advances in process control, such as applying Economic Model Predictive Control (E-MPC) to flotation circuits, have been shown to increase recovery by up to 20% while maintaining concentrate grade. Hernández *et al.* (2024) [17] emphasize the combined importance of optimized reagent dosing and modern control methods in flotation practice. Supporting this, recent studies indicate that coupling the Jameson Cell with intensified devices, such as the Reflux Flotation Cell (RFC), significantly improves ultrafine chalcopyrite recovery from tailings (<53 μm), thereby expanding the usefulness of modest reagent strategies in more complex circuits [18].

4. Conclusion

The dilution cleaning tests showed that the performance of Jameson Cells at the Kamoa–Kakula concentrator can be notably improved through careful reagent management. Hydrofroth 5008 increased recovery but lowered selectivity, confirming its limited suitability for applications where concentrate grade is critical. Flotanol offered a more balanced impact, enhancing both grade and recovery at moderate doses, though overdosing led to similar entrainment issues. The best results were achieved with the SIBX and SNF522 combination, which consistently reached high copper recoveries (>95%) and improved concentrate grades while reducing copper in tailings. These findings highlight that reagent synergy and dosing control are essential for optimizing metallurgical performance in Jameson Cells. Future research should focus on pilot-scale validation and long-term plant trials to develop reagent strategies tailored to ore variability and operational stability.

Authors' Contributions

Conceptualization and methodology, B.O.-N, R.-C; formal analysis and investigation, B.O.-N, R.-C; writing-original draft preparation, B.O.-N, C.M-M, M.A-M, A.K-B, A.M-K; writing-review and editing, B.O.-N, C.M-M, M.A-M, A.K-B, and A.M-K. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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