Illustrating the Power of Switchable Frothers: Improving Concentrate Grades and Downstream Cu-Mo separations

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Introduction

The need for the mining industry to meet current and future global demand of metals is increasingly becoming critical, especially since operations must process larger tonnages of lower grade ores to maintain production. Current flotation practices, both from equipment, operational, and reagent aspects must evolve in order to ensure that metal recoveries and production can be maximized while producing saleable concentrates. In particular, plants processing increased throughputs often have to operate at coarser particle sizes necessitating the use of stronger flotation reagents in the rougher stage to ensure acceptable recoveries. However, using these strong reagents, particularly frothers result in very persistent, stable froths downstream in the cleaner operations resulting in poor quality and lower grade concentrates. These strong frothers also affect downstream solid-liquid separation. Specifically, for Cu-Mo plants that are important sources of global copper and molybdenum supply, the strong frothers used in the generation of bulk Cu-Mo bulk concentrates also affect downstream Cu-Mo separation which results in inefficiencies in production of separate Cu and Mo concentrates.

Syensqo's Transfoamer™ switchable frothers behave as strong frothers in the rougher circuit enabling operations to maximize rougher recoveries, but switch to weaker frothers with the pH increase in the regrind/cleaning stages. This paper highlights the beneficial application of the switchable frothers to improve concentrate quality and grades in the cleaning stages which facilitates better Cu-Mo separation. Using a case study at a North American Cu-Mo plant, we illustrate the critical impact of the quality of bulk Cu-Mo concentrates on Cu-Mo separation efficiency. Using a combined plant-laboratory study, we demonstrate that bulk concentrates generated in the plant using the switchable frothers result in much improved recovery and upgrading of Mo in the Cu-Mo separation stage, improved insoluble rejection, reduced misreporting of Cu into the Mo concentrate (hence higher Cu production), and much improved overall efficiency in the process.

TRANSFOAMER™ Switchable Frother Technology: Background and Performance Benefits

Recently, Syensqo has developed a novel frother technology that enables maximizing the flotation of coarse particles in the rougher without causing overfrothing issues in the cleaners. The Transfoamer™ technology relies on a pH triggered transformation in chemistry: the product acts as a very strong frother at rougher pH range (8-10.5). It is able to float the coarse particles, and as the pH increases from the rougher to the cleaners stages (10.5-12.0), it switches to a weaker frother and allows for more efficient upgrading of the rougher concentrate.

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The switch to weak frother, once it happens, is irreversible. The rate of switching from the strong to weak frother is a function of pH. At pH 11.5, it can take about 30 minutes to complete the switch from strong to weak. The switchable frother concept enables a more aggressive and stable operating regime in the roughers that is not possible with formulated frothers which typically cause overfrothing issues in the cleaners resulting in poor upgrading.

The Transfoamer™ product portfolio consists of various frothers developed for different mineralogies and grinds. Specific products have been developed for plants treating coarser grinds as well as those processing problematic clay ores with bimodal size distributions where losses in both fines and coarse particles are typical. The products have been trialed at multiple global Cu-Mo-Au operations with very promising results. One of the key beneficial attributes has been the ability of the plants to reduce circulating load in the cleaning circuits with the Transfoamer™ technology. Many plants, on occasion, send the cleaner scavenger product to tailings to reduce the solids density in the cleaners; having a weak frother in the cleaning circuit has helped to avoid this situation and the resulting metal losses. Finally, plants with thickener performance issues due to overfrothing have observed improved thickener overflow clarity, and better overall solid-liquid separation resulting in improved water availability.

Improving Bulk Circuit Cleaner Concentrate Quality and Cu-Mo Separation with the TRANSFOAMER™ Technology

Syensqo's Transfoamer™ T-200 frother has been tested at a large North American Cu-Mo operation with promising results both in the rougher and cleaner stages of the bulk Cu-Mo circuit. The main parameters driving Cu recovery in the plant are head grade which ranges between 0.2 – 0.6% Cu and the ratio of Acid Soluble Cu to Total Cu which ranges between 5 and 30%. Plant data showed that the T-200 improved the rougher recovery which was attributed to better collection of poorly liberated particles in low-grade ores and mildly hydrophobic particles in ores with higher oxide copper content. The general plant flowsheet is shown in Figure 1.

The Cu-Mo plant processes ~100,000 tons per day and employs one comminution/classification circuit that feeds two parallel, independent rougher-cleaner sections A and B. The bulk Cu-Mo concentrates from the two sections are combined, thickened, and processed in the downstream Cu-Mo separation plant to produce separate Cu and Mo concentrates by depressing the Cu sulfides and pyrite using depressants while floating the naturally hydrophobic molybdenite.

The plant's main metallurgical goals are to maximize copper and molybdenum production while minimizing the levels of impurities in the concentrates, mainly insols (proxy for non-sulfide gangue minerals reporting into the concentrate), Pb, and Zn. Previous plant testing of Transfoamer™ T-200 frother as a full replacement of the incumbent blended frother in the whole plant (both sections A and B) indicated better rejection of insols in the bulk Cu-Mo circuit cleaners which resulted in a higher Cu and Mo concentrate grades. Additionally, better efficiency was reported in the downstream Cu-Mo separation process. However, the specific contribution of the Transfoamer™ T-200 in comparison to the incumbent frother was not quantified. In the current combined plant and lab study, the incumbent blended frother was used in Section A of the plant while Transfoamer™ T-200 was

applied in Section B. The dosage for both frothers was 20 g/t. The plant was run for 10 days to ensure that no residual incumbent frother was present in Section B that was using the Transfoamer™ T-200.

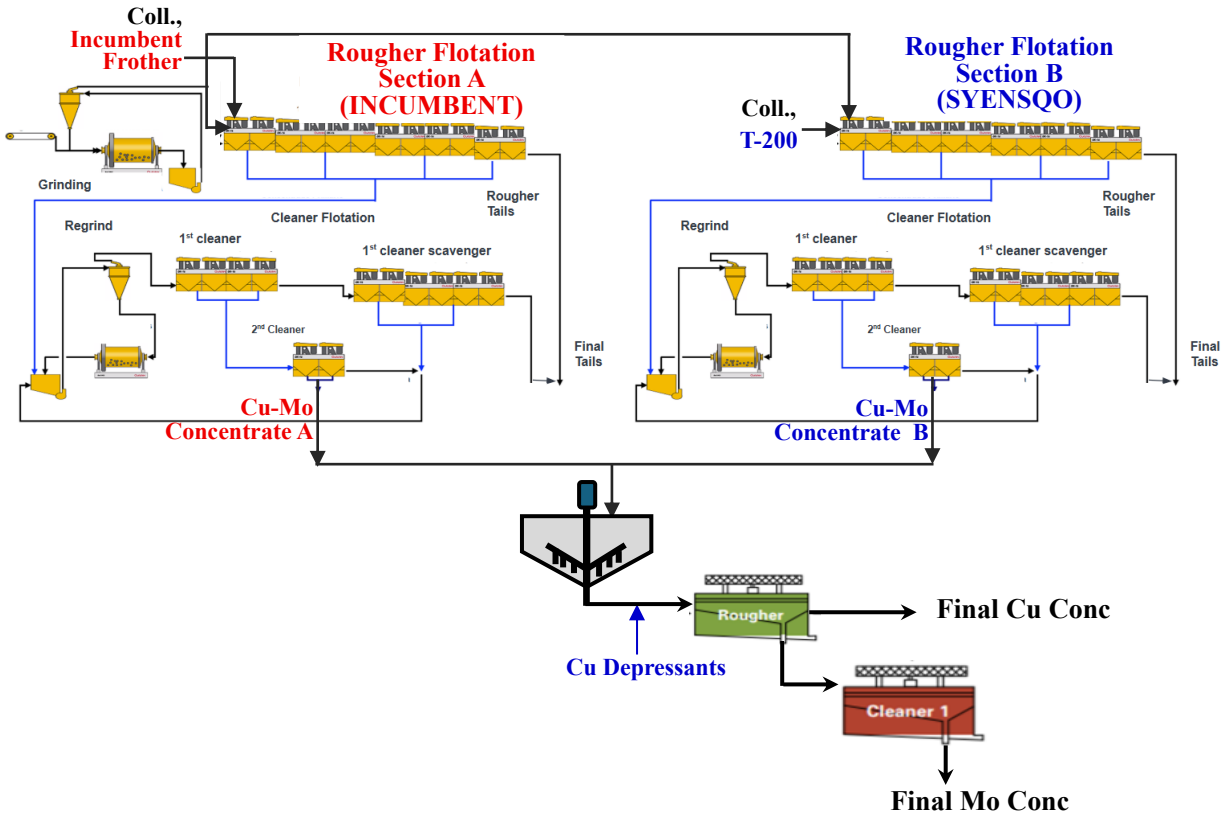

Figure 1: *Simplified Cu-Mo plant flowsheet illustrating sequence for Cu-Mo bulk flotation in two parallel rougher-cleaner sections and Cu-Mo separation of the combined bulk concentrate to produce separate copper and molybdenum concentrates*

The Cu-Mo 2nd cleaner concentrates from each section of the plant were then sampled separately over a period of 3 months for laboratory Cu-Mo separation tests. The samples were typically tested immediately after sampling to minimize aging. The same depressant combinations as those used in the plant were used during the laboratory tests, thus the only variable was the type of frother (incumbent blended frother or Transfoamer™ T-200) used to generate the bulk concentrates in the plant. This allowed us to determine the impact of the frother on the efficiency of Cu-Mo separation.

Cu-Mo Bulk Circuit Cleaner Concentrate Quality

Figure 2 (left) shows the Cu grades of the 2nd cleaner concentrates obtained in Section A using the incumbent frother and Section B using the Transfoamer™ T-200 frother. The data points correspond to samples taken in the plant over a period of 3 months. The lowest average Cu concentrate grade of 21.6% was obtained with the incumbent blended frother while the T-200 achieved a higher grade of 23.0% Cu. An analysis of the grades of the main components in the concentrates indicated that the insols were the main minerals impacting the bulk concentrate grades. Figure 2 (right) shows that the higher insols grade achieved with the incumbent frother (8.2% vs. 6.7 for the T-200) was indeed the main reason for the lower Cu grade. As expected, the incumbent frother persisted into the cleaners and created strong frothing conditions not conducive for effective upgrading. On the other hand, the

switching of the T-200 Transfoamer™ from a stronger frother in the roughers to a weaker frother in the cleaners permitted better drainage and rejection of the insoluble gangue minerals underscoring its ability to enhance concentrate grades. The Mo concentrate of the bulk concentrates were marginally higher with the T-200 (2.77%) in comparison to the standard frother (2.62%).

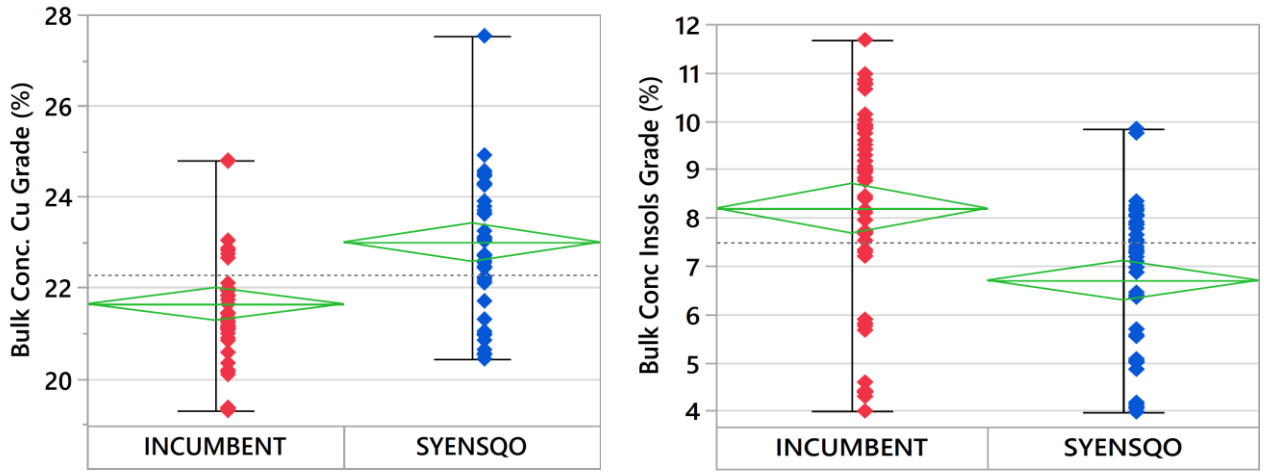

Figure 2: *Cu grades (left) and insols grades (right) of the Cu-Mo bulk concentrates produced with the incumbent (standard) reagent suite and Syensqo's Transfoamer™ T-200 technology.*

Efficiency of the Downstream Cu-Mo Separation Process

Cu-Mo separation laboratory tests (rougher only) were conducted on the separate bulk Cu-Mo co concentrates from Section A and Section B using a combination of sodium hydrosulfide (NaSH) acting as a Cu sulfide depressant at two dosages (3.1 and 4 kg/t) and AERO® NR-7370, Syensqo's new NaSH replacement depressant at a dosage of 1.6 kg/t. The depressant dosages are expressed on the basis of the Cu-Mo separation plant feed rate not the primary tonnage. No additional frother or Mo collector were required as these are typically carried over from the bulk Cu-Mo circuit.

The main metallurgical objective in the Cu-Mo separation rougher stage is to maximize Mo recovery (>90% recovery), minimize the amount of Cu reporting to the Mo concentrate, achieve Mo grade target of >15%, and produce a final Cu concentrate (the depressed stream) grading >23% Cu. In the actual Mo plant operation, the rougher concentrate is upgraded in 4 cleaning stages to produce a final Mo concentrate grading ~>53% Mo.

The rougher concentrate Mo recoveries and grades are shown in Figure 3 below. Both the Mo recoveries and grades were higher for the bulk concentrates produced in Syensqo's Section B that used the Transfoamer™ T-200 frother. The Mo recovery was higher for Syensqo's T-200 frother by 1.84 percentage points while the Mo grade improvement by the T-200 was much more significant (+7 percentage points). The Mo grade achieved with the incumbent frother was consistently below the target rougher Mo grade of 15%. It is evident that the improvement in the bulk concentrate quality obtained in the bulk circuit with the Transfoamer™ T-200 translated to better Mo flotation and grade in the Cu-Mo separation process.

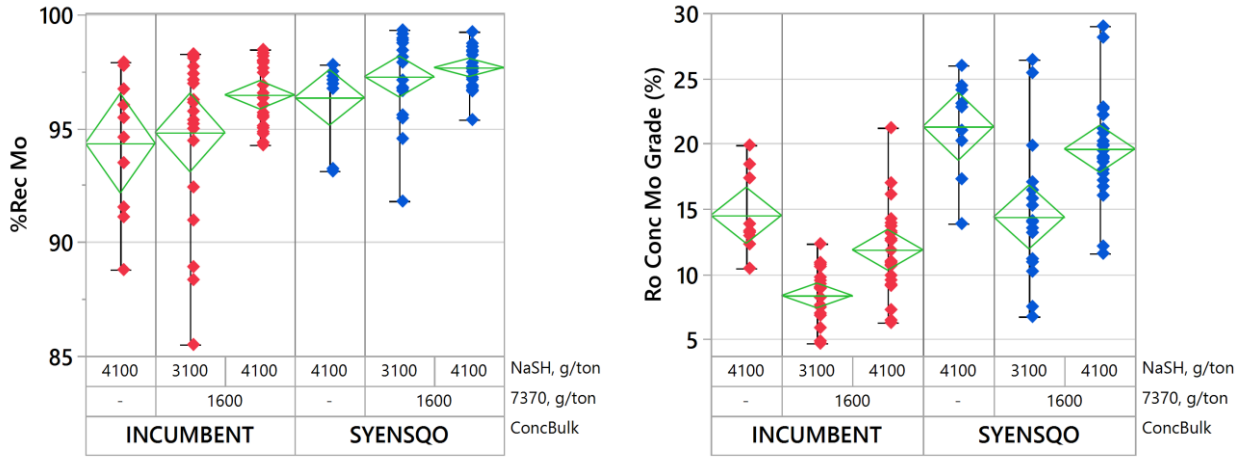

Figure 3: *Mo recoveries (left) and Mo grades (right) of the Cu-Mo separation rougher stage concentrates for Section A (incumbent frother) and Section B (Syensqo's T-200) bulk concentrates.*

Whereas the depressants are essential in depressing Cu sulfides and pyrite in the Cu-Mo separation rougher stage, the weak properties of the T-200 are essential in minimizing entrainment of several minerals into the Mo concentrate including impurities such as insols, Zn, Pb, and also Cu sulfides that may be depressed but are fine and easily transported into the froth zone. Minimizing entrainment is especially important for this Cu-Mo plant that targets very high Mo recoveries which requires high mass recoveries. As an example, Figure 4 below indeed shows that less insols (-2.2 percentage points) and Zn (-17 percentage points) reported into the Mo concentrate with the Transfoamer™ T-200 frother compared to the incumbent frother.

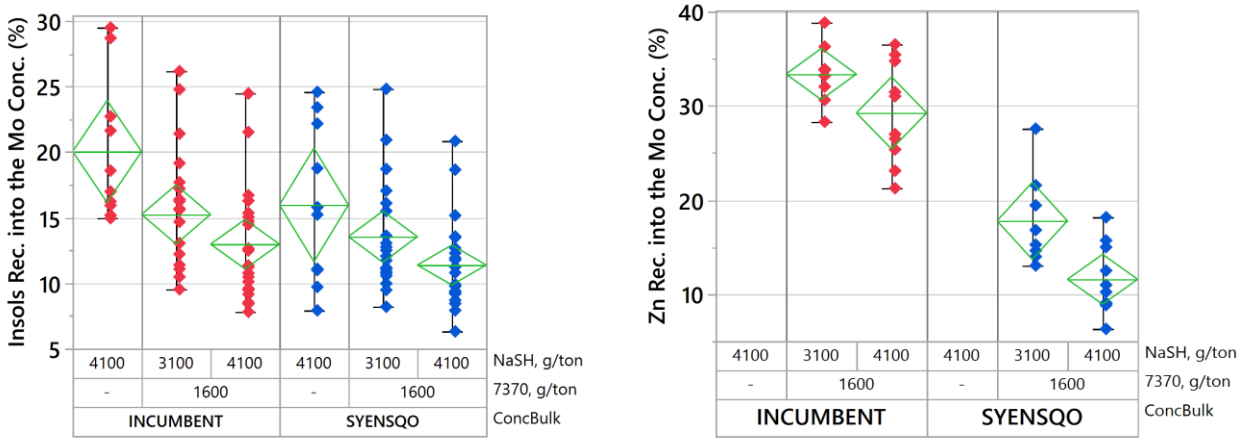

Figure 4: *Insols (left) recoveries and Zn (right) recoveries into the rougher Mo concentrate for Section A (incumbent frother) and Section B (Syensqo's T-200) bulk concentrates.*

As can be seen in Figure 5 below, the ability of the T-200 to improve froth drainage and thus minimize entrainment of fine depressed Cu sulfides into the Mo concentrate resulted in significantly less Cu misreporting into the Mo concentrate and instead reporting into the final concentrate as is desired. Copper recovery into the Mo concentrate was reduced by about 8 percentage points with the use of the T-200 frother. The implication of this is increased daily Cu production. Additionally,

sending less Cu into the cleaners, as was achieved with the T-200, resulted in lower recirculating load in the cleaner circuit which significantly improved the Mo concentrate upgrading efficiency.

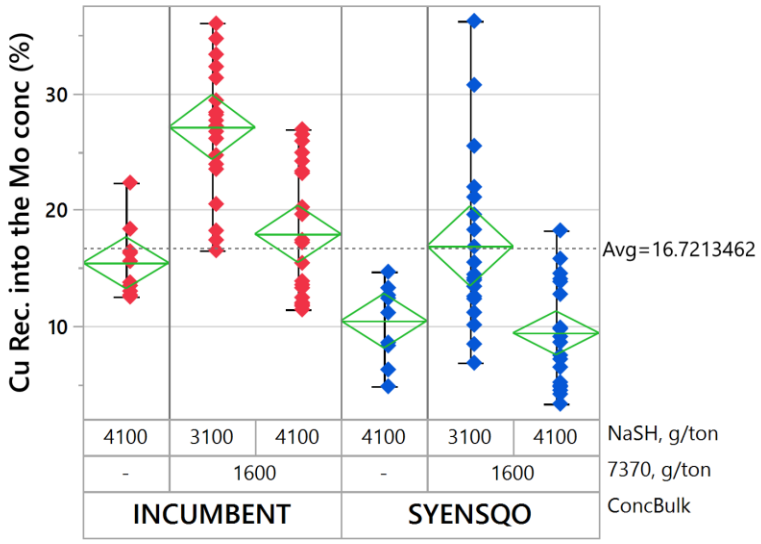

***Figure 5**: Cu recovery into the rougher Mo concentrate for Section A (incumbent frother) and Section B (Syensqo's T-200) bulk concentrates.*

Conclusions

Mines are looking to increase throughput in order to maintain or increase metal production in the face of declining ore grades. This often results in a coarse particle size distribution in the flotation feed. Floating coarse particles requires strong frothers, which carry over to the cleaners and downstream metal separation circuits causing overfrothing and poor concentrate upgrading. Solutions to these problems often include blends of "strong" and "weak" frothers, invariably leading to compromises in either the rougher or cleaner circuits. Syensqo's novel Transfoamer™ switchable frother technology has shown, on industrial scale, the ability to be strong in the rougher circuit, but weaken in the cleaner circuit as the pH is increased. The technology has enabled Cu-Mo-Au plants to improve rougher recoveries, reduce cleaner circulating loads, improve concentrate upgrading resulting in higher grades.

The case study at a large North American Cu-Mo operation illustrates the Transfoamer™ technology's ability to redefine the possibilities available for plants to maximize recoveries in the Cu-Mo bulk circuit while also improving the quality of the cleaner concentrates which then significantly improves the Cu-Mo separation process. Compared to the incumbent blended frother, the Transfoamer™ T-200 frother produced a cleaner, higher grade Cu-Mo bulk concentrate in the plant. During laboratory Cu-Mo separation of the Cu-Mo bulk concentrates produced with the incumbent and T-200 frother, significantly better metallurgical parameters were obtained with the higher quality concentrate including high Mo recovery and grade, less impurities in the Mo concentrate, and most importantly less misreporting of Cu into the Mo concentrate implying higher Cu production.