A NEW APPROACH TO DESIGNING FLOTATION FROTHERS

HEARN, S.¹, MUCHON, H.², BOSKOVIC, S.³
¹Huntsman Corporation, Woodlands, e-mail: steve_hearn@huntsman.com
²Huntsman Química Brasil, São Paulo, e-mail: herminio_muchon@huntsman.com
³Huntsman Australia, Brooklyn, e-mail: sasha_boskovic@huntsman.com

ABSTRACT

Huntsman’s approach to frother technology has been to utilize fundamental molecules which the company produces and to design specific frothers for unique applications. This paper will explain the company’s philosophy and will bring in specific case studies which illustrate how this works in practice at key mine sites.

KEYWORDS: mineral processing; flotation; chemical reagents; frothers.

RESUMO

A tecnologia de espumantes abordada pela Huntsman tem sido utilizar as principais moléculas que a empresa produz para desenvolver espumantes especiais para aplicações específicas. Este artigo irá explicar a filosofia da empresa e trará particulares estudos de caso que ilustram como isso funciona na prática em mineradoras.

PALAVRAS-CHAVE: processo mineral; flotação; reagentes químicos; espumantes.
1. INTRODUCTION

Froth flotation has of course been around for many years in one form or another, certainly since the late 19th century. Every country with a mining history has its own version of the story of the miner’s wife, washing his dirty clothes and noticing that the bubbles were darkened with the mineral particles sticking to them. One well know flotation machine manufacture even claims its distinctive flotation impeller design has its origin in the implement that lady wielded to wash those clothes in the tub!

Frother chemistry has advanced considerably since that time, particularly with the custom manufacture of polymers, rather than the use of commonly available products like soaps and this paper explains how they can be tailored for certain applications. This paper explains how molecules are modified and combined to take advantage of certain properties or characteristics in providing strong versus weak frothers. Examples are given, with the specific adoption of two of these frothers at Canadian mines, in recent years, showing their specific benefits to those situations. This shows that innovative manufacturers are constantly refining their products in order to offer more cost effective and environmentally acceptable frothers.

2. FROTH FLOTATION IN MINERAL PROCESSING – A HISTORIC PERSPECTIVE

William Haynes patented a process in 1869 for separating sulfide and gangue minerals using oil and called it bulk-oil flotation. The first successful commercial flotation process for mineral sulfides was invented by Frank and Stanley Elmore. The Glasdir copper mine at in North Wales was bought in 1896 by the Elmore brothers. In 1897, the Elmore brothers installed the world’s first industrial size commercial flotation processes for mineral beneficiation at the Glasdir mine. The flotation process was independently invented in the early 1900s in Australia by Charles Vincent Potter and around the same time by Guillaume Daniel Delprat. This process (developed circa 1902) did not use oil, but relied upon flotation by the generation of gas formed by the introduction of acid into the pulp. In 1902, Froment combined oil and gaseous flotation using a modification of the Potter-Delprat process (Lynch, Harbort and Nelson, 2010).

3. THE FROTH FLOTATION PROCESS

Froth flotation is undoubtedly the most commonly used method of mineral recovery and upgrading, currently estimated to being used to treat some 10 billion tons of ore, annually, worldwide. A froth flotation system will consist of a flotation machine, with either a mechanical impellor or rotor or pneumatic air spargers. The purpose of either system is to maintain suspension of the solids present in the pulp and to introduce air in the form of fine bubbles which attach themselves preferentially to desirable particles. Chemical addition will in turn affect the amenability of certain particles to attach themselves to the bubbles. This combination of the mechanical as well as the chemical processes has led interpretation of this as a physio-chemical process, with both elements being equally important. It is therefore somewhat of a mystery that the flotation equipment manufacturers and the chemical manufacturers rarely if ever seem to communicate with each other. Surprising, as the former companies claim to
make smaller and more even sized bubbles and the latter to aid in making more stable bubbles! As flotation machines seem to get larger almost annually (a 630 m³ cell is now offered by one manufacturer), the question should be asked as to whether the bubbles will be adequate to carry mineral across the greater surface area in those larger cells? Clearly, the effective creation, through introduction of air down the flotation machine shaft or through the air spargers, of as many bubbles as possible, is the realm of Outotec, FLS, Eriez and others – the physio part of the process. The subsequent modification of those bubbles to provide best case conditions for mineral collection and transportation is the territory of the chemical companies.

4. THE CHEMICAL COMPONENTS OF FLOTATION

Almost all flotation systems will involve the introduction of collectors and frothers. The most common collectors are the xanthate class with dithiophosphates and thionocarbanilamides being generally classed as secondary or complimentary collectors. Amines and fatty acids are also important in the flotation of industrial (nonmetallic) minerals. This brings us to frothers, the subject of this paper.

5. FROTHERS

Frothers are heteropolar surface-active compounds that lower the surface tension of water and have the ability to adsorb on the air bubble–water interface as illustrated in Figure 1. (Bulatovic, 2007). Surface tension also affects the size of the air bubbles and this is a most important characteristic as many small bubbles have a combined greater surface area than larger bubbles, with a given volume of induced air into a flotation cell.

![Figure 1. Frother adsorbing on to the bubble surface.](image)

The demand on frothers in a flotation circuit is a high one; (Mello and Laskowski, 2005) frothers are asked to:

- Prevent bubble coalescence;
- Increase strength of frother so that attached particles don’t drop off whilst rising through the pulp, or whilst travelling across the float cell surface to the overflow, but then…;
- Immediately collapse as they hit the launder, to reduce over-frothing;
- Be wet enough to aid draining interstitially within the froth to remove entrapped gangue;
• Slow the rise rate of bubbles to enhance particle capture probability;
• Have a moderate persistency such that return water streams only contain small amounts of carry over frother;
• Not have a lasting harmful effects on downstream marine or plant life and do all the above at a cost effective dose rate!

Based on the effectiveness of frothers at different pH values (i.e. the pH at which the frother is most effective), they can be divided into: *acidic*, when frothing ability is reduced with an increase in pH from acid to alkaline and *neutral*, when the performance of the frother does not depend on pH value of the pulp. The acidic frothers belong to two basic groups: phenols (cresol, pine oil) and alkylsulfonates (surfactants) but are relatively unimportant compared to the more important neutral type of frothers. These frothers are divided into the following groups: cyclic alcohols, aliphatic alcohols (MIBC, very commonly used), alkoxy paraffin’s (TEB which only really used in RSA and Australia) and glycols. Various common groups of frother are shown in Figure 2.

Frothers are heteropolar surface-active compounds containing a polar group (OH, COOH, C_O, OSO₂ and SO₂OH) and a hydrocarbon, capable of adsorbing in the water–air interface (Bulatovic, 2007). The frother molecules are arranged at the air–water interface such that the hydrophilic or polar groups are oriented into the water phase and the hydrophobic or nonpolar hydrocarbon chain in the air phase (See Figure 3).

The individual chemistries making up a frother product will contribute to impart either an overall hydrophilic or hydrophobic characteristic to the molecule. The ratio of the two parts (summed) is designated a HLB (hydrophile-lipophile balance) number. Simply put, this number gives you a measure of the solution characteristics of the frother, and how it is likely to perform at the gas/liquid interface relative to other frothers.
Figure 3. Shows how the HLB no. is derived.

Laskowski, 2004 illustrated these two sets of properties by means of a graph (Figure 4), hence showing HLB number against the MW. Certain well known commercial frothers can be shown as plots on such a graph.

Figure 4. Shows HLB nos. and MW’s of some common frothers.

6. MANUFACTURING THE RIGHT MOLECULE

The industry will be familiar with such comparative terms like “strong”, “weak”, “wet” and “dry” when comparing and selecting frothers. “Strong” vs. “weak” frother can be partly explained in terms of frother chemistry and MW, with alcohols, such as MIBC, being termed weak and polyglycol ethers being termed strong. Simply put, a strong frother will often be used when pulling a rougher float circuit for maximum recovery from a low grade ore, whereas a weak frother might be used when selectivity is the key.

Similarly an explanation of wet frothers versus dry would describe froth’s washing capability, allowing unattached particles to flow along the plateau border thereby removing gangue material from the bubbles (Figure 5). (Khoshdast and Sam, 2011).
Figure 5. Interstitial regions between froth bubbles, which allow drainage.

So, the optimum frother type depends on a balance of molecular weight and HLB. In identifying specific desired characteristics of various frothers, a “map” can be drawn up (Figure 6) which plots these properties and thereby acts as a guide to which frothers might be selected based on the comparative property requirements.

As a manufacturer, this map also becomes an important tool in identifying “gaps” in the frother range.

![Frother “map”](image)

Figure 6. Frother “map”.

7. CASE STUDIES

7.1. Mount Polley, in BC, Canada, is an open pit porphyry copper-gold mine

The flotation circuit consists of a conventional rougher/scavenger circuit, followed by further upgrading in a cleaner circuit to produce the final concentrate product. Main reagents used were PAX and MIBC. In 2011, it was decided to try alternate frothers and POLYFROTH® W22 was one of those tested at site. POLYFROTH® W22 is a polyoxyalkylene alkyl ether frother of low molecular weight. Originally it was developed as an alternative for MIBC in coal flotation. POLYFROTH® W22 is oil soluble and partially soluble in water, producing fine bubbles of uniform structure that
break down readily in launders. MIBC in comparison is a branched alcohol that is sparingly soluble in water and more hydrophobic, producing less tightly knit froths with thin bubble membranes that give more selective froths with less persistence. Whilst these two frothers share some similarities, key differences lie in their efficacy and handling properties and these were noted by the operators during the trial.

The trial at Mount Polley lasted 10 months and was conducted at the Mount Polley Concentrator after positive initial results were obtained from a number of smaller randomized block plant trials (the initial plant trial operated with POLYFROTH® W22 over 24 hrs. for the total period).

The averaged plant trial copper recovery data using both frothers is given in Figure 7. Analysis of the copper recovery and concentrate grade data indicated that W22 performed well and gave similar metallurgical performance to MIBC over comparative trial periods, i.e. 79.42% copper recovery for W22 versus 79.27% copper recovery for the MIBC baseline. The averaged W22 frother consumption was significantly lower than resulting in a decrease of at least 40% in overall frother usage. Figure 8 shows the dosage decrease from an average of 25 g/t with MIBC to 12 g/t with POLYFROTH® W22 over the trial period. (Note: POLYFROTH® W22C is shown in the diagram as this was the earlier version at Mount Polley Mine).

The trial outcome clearly demonstrated that a polyoxyalkylene alkyl ether frother could replace MIBC at equivalent metallurgy for significant reduction in dosage and offer additional operational benefits including:

- Improved froth stability, froth level controls and concentrate flows in the Rougher, Scavenger and Cleaner Column cells of the circuit;
- Improved froth cover in the Rougher-Scavenger cells, allowing concentrate to migrate to the cell lips more easily;
- Drier froth appearance and hydrophobic solution characteristics, reducing the carry-over of gangue slimes into the concentrate;
- Less column air required to achieve cleaner recovery as the froth was more stable with POLYFROTH® W22;
- Deeper froth depths in the cleaner columns allowed masking of plant surges and level control problems which were apparent with MIBC running at shallower froth depths;
- Additionally, POLYFROTH® W22 has a higher flash point than MIBC and is regarded as non DG (Dangerous goods).

The plant trial at Mount Polley resulted in the utilization of POLYFROTH® W22 at the mine and the circuit has been running over four years under this current situation, consistently demonstrating value in dosage efficiency. (A footnote to this Case study is that Mount Polley suffered a major tailings dam failure in 2014 but testing did not detect any appreciable levels of POLYFROTH® W22 in the spilled material. The mine is expecting to restart during 2015.)
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Figure 7. Mount Polley’s 18 month frother evaluation.

Figure 8. Mount Polley’s 18 month frother consumption.

7.2. Polyfroth® W31 development

Dowfroth 250 was almost ubiquitous as a medium strength frother and was widespread (including copycat versions) across industry. In the mid 2000’s, Dow announced they would discontinue production and there was a search initiated by the mining industry to find a robust alternative frother.

Huntsman considered that its UNIFROTH® 250 CM, which had found extensive use in Eastern Canada in nickel processing might provide a starting point for this development.

UNIFROTH® 250 CM has a similar chemical make up to Dowfroth 250C, but when run at selected operations, had shown lower froth power, shown in Figure 9, resulting in higher dosage requirements.

Extensive further work was completed by Huntsman to modify the UNIFROTH® 250CM to match the chemical and the resulting product is POLYFROTH® W31.
One of the first companies looking for this Dowfroth alternative was Teck’s Highland Valley Copper (HVC) mine in BC, Canada. After extensive testing of the new frother at the site, POLYFROTH® W31 was introduced commercially at HVC in 2010 where it proved successful on this relatively coarse ore and has now run for several years, proving itself a robust replacement (Welsby, 2014).

In 2014, HVC replaced hundreds of smaller rectangular flotation cells with 200 m³ Tank Cells. There was an initial concern that froth had to be robust enough to allow for stable transfer of the mineral loaded bubbles across a wider cell width, prior to discharge. This concern proved to be unfounded and the frother has been used in a seamless fashion during the transition from the original circuit to the current one using many fewer but larger cells.

8. CONCLUSIONS

Industry has been slow to stop using such industry standards, like MIBC, but whether it’s because of safety issues (like MIBC’s low flash point, or non-availability of “old standards”, like Dow 250C), it can be seen that innovative manufacturers have come up with better alternates in recent years.

9. REFERENCES


Welsby, SDD, Pilot scale frother testing at Highland Valley Copper CMP Ottawa 2014.