Froth Phase Control with Adjustable Radial Froth Crowders – The Key to Higher Recovery

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Abstract

Froth flotation has been the heart of mineral beneficiation for over a century. Over the years, developments have been made in flotation cell design, size, and in many other aspects of flotation technology. Despite the overall effectiveness of these improvements, valuable mineral particles are often lost along with waste material. These particles are lost when the froth recovery process within a flotation system is not designed for variable froth conditions seen in plant operations.

Both the amount of froth generated and the type of froth in a flotation cell change as concentrate is removed down a row of cells. Traditionally, froth recovery has been designed using a froth carry rate averaged over the entire row of flotation cells with a static amount of open area at the top of the cell. The size of flotation cells has increased dramatically over the past two decades, making improvements in launder and froth crowder design necessary to increase the recovery efficiency in the froth zone. To address this issue, FLSmidth has created and implemented Adjustable Radial Froth Crowders that allow flotation operators to have more control over froth recovery and optimize the process for the variability of froth conditions.

The theory behind the need for froth crowding and observations from practical application of Adjustable Radial Froth Crowders will be presented and discussed.

1. Introduction

Froth recovery is essential to flotation. It is a key part of the overall performance of flotation cells and if mismanaged, can result in a large recovery and financial losses. If done well, along with the rest of the flowsheet, one can better optimize their circuit resulting in increased recoveries and efficiences. These increased efficiences will also help save precious resources such as water and energy. The purpose of this paper is to present some options that can be used to optimize froth recovery and numerical examples of doing so.

2. Froth Recovery

2.1. What is Froth Recovery?

There are multiple things that need to occur in a float cell in order for recovery to occur. The desired mineral must make contact with a bubble, attach to the bubble, and stay attached long enough to travel up the cell, through the froth and into the concentrate launders. The collection process from the froth phase to launders is known as froth recovery.

Froth is a three phase mixture of solids, water, and gas. The properties of the froth can vary considerably depending on things like: solids particle size, type of solids, concentration of solids, reagents used and their concentration, etc... Typically, the desired minerals make their way to the top of the froth bed until they are collected into the froth launder.

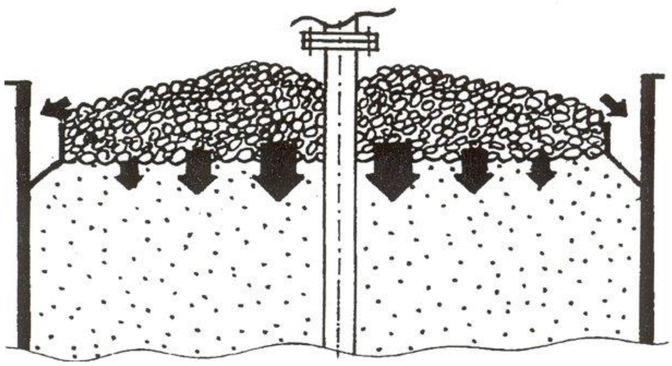

Figure 1: Illustration of Froth and Pulp phase in a Float Cell.

2.2. Factors that affect Froth Recovery

2.2.1. ***Froth Chemistry***

Froth Chemistry is one of the main starting points to maintaining a suitable froth and facilitating an effective froth recovery. According to Cytec's (Solvay) Mining

Chemicals Handbook, "Frothers were amonght the first reagents developed for mineral concentration by froth flotation; they remain a critical part of the suite of reagents used today. They must have the property of generating a froth that is capable of supporting and enriching a mineral." Typically froths must have certain charactaristics such as:

1. The froth must have surface film properties that will allow the valuable mineral to attach, but resist the attachment of gangue minerals.
2. Be stable enough to support a considerable weight of mineral and mobile enough to transport that mineral to the collection launder.
3. It must be sufficiently transient for the bubbles to break down and reform continuously, so that the water and gangue minerals drain back into the pulp.
4. It must be stable enough to form a froth when air is introduced during different stages of flotation, but not so stable that it will not break down in the launders and sumps.

"The importance of achieving an optimal froth bed cannot be overemphasized, since this is where all the enrichment of the valuable minerals occurs as a result of hydrophilic gangue particles draining back into the pulp while the hydrophobic valuable minerals remain in the froth."

There are two main types of frothers in use today: synthetic alcohols and glycols. They each have their own characteristics that generate different types of froths depending on what the operator is targeting. Great care should be taken in selecting the type, dosage, and dosage points for frothers used.

*2.2.2. **Froth Travel Distance***

Froth travel distance, as the name implies, is the distance that a particle must travel to reach a collection launder once arriving at the surface of the froth bed. The longer the travel distance, the higher the probability that the particle will become detached from the bubble and lost back into the cell. The shorter the distance, the better chance of the particle arriving to the concentrate launder. Typical recommendations are that the maximum froth travel distance should be less than one meter to minimize the risk of drop back.

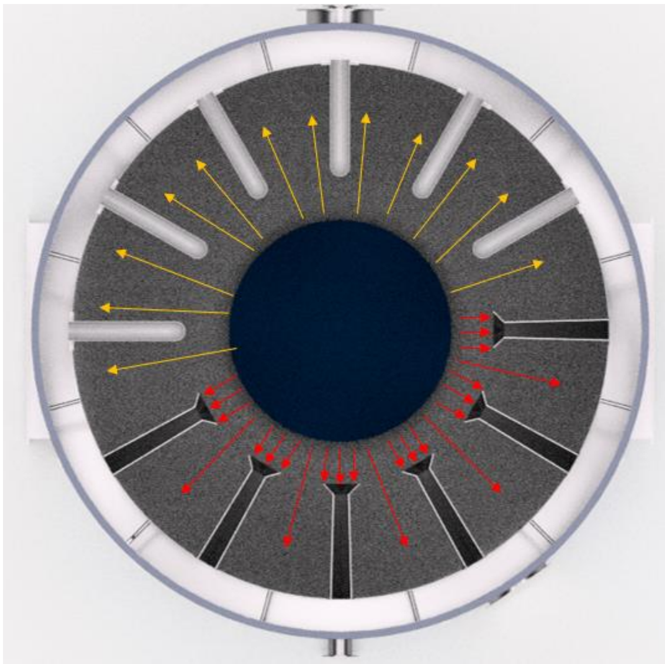

Figure 2: Top of a Float Cell with Illustrated Froth Travel Distances and corresponding radial launders.

*2.2.3. **Lip Loading and Froth Carry Rate***

From a volumetric standpoint, froth is mostly made up of air. There is a physical limit to how much material that froth can support. The rate of froth that can physically flow up to the surface of the cell and over the launders also has a physical limit. This leads to two factors that are commonly used when evaluating cell sizing in flotation applications. They are Lip Loading and the Froth Carry Rate.

Lip Loading is the solids flowrate into the launders divided by the wetted lip length at the launder froth interface. Figure 3 shows (bolded in blue) an illustration of the lip length for a typical cell. To avoid any froth recovery restrictions due to lip length, a rule of thumb is that lip lengths shouldn't exceed 1.0 – 1.5 t/m/hr. However, as with many cases in flotation, there are always exceptions to this rule and each case needs to be evaluated accordingly.

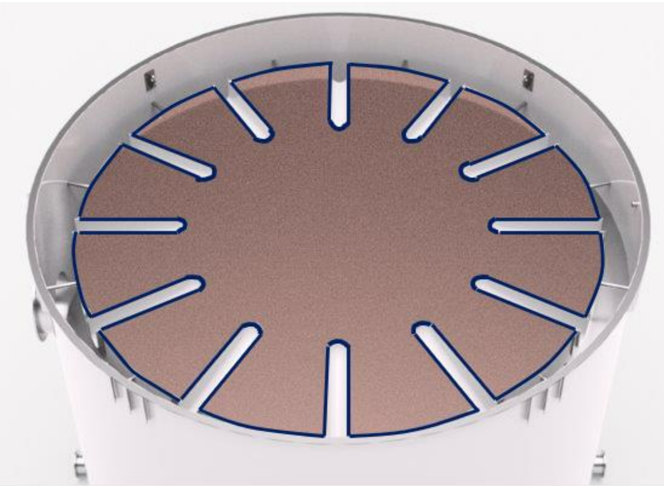

Figure 3: Illustration of Lip Length and surface area of a Flotation Cell (Outlined in Dark Blue)

$$\frac{\text{Froth flowrate into the launder}}{\text{Wetted lip length at launder froth interface}} \quad \frac{(\text{TPH})}{(\text{m})}$$

Equation 1: Lip Loading Equation

Froth Carry Rate (FCR) is the solids flowrate into the launders divided by the cross-sectional area at the surface of the cell. Figure 3 shows the cross-sectional surface area of a typcial float cell.

$$\frac{\text{Froth flowrate into the launder}}{\text{Cross-sectional area}} \quad \frac{(\text{TPH})}{(\text{m}^2)}$$

Equation 2: Froth Carry Rate Equation

Rules of thumb also exist for the FCR. For most common sulfide flotation applications the following rates are recommended:

- Rougher: 0.8-1.5
- Scavenger: 0.3-0.8
- Cleaners: 1.0-2.5

These values are a good starting point to look at when evaluating whether or not adjustments need to be made in the float cells/circuit to optimize the froth recovery. A high FCR would indicate that there is too much material attempting to leave the cell, and that froth recovery will be restricted due to the physical limitations in the cell. This is common at the beginning of rougher circuits due to the large amount of readily floatable solids.

A rate that is too low indicates that there is too much surface area at the top of the cell for the amount of material that is floating. This case will result in a froth that is unstable and will be difficult to maintain a sufficient froth bed. This is common at the end of rougher and scavenger circuits where most of the easy floating material has been removed and only a small amount of more difficult-to-float material is available.

3. Optimizing Froth Recovery

Assuming that froth chemistry and dosages have been optimized, there are a few other "mechanical" options that can be implemented to optimize froth recovery.

3.1. Launders

As mentioned in the previous section, froth travel distance and lip loading are two factors that can be used in launder design and implementation.

As the size of float cells has significantly increased over the past 30 years (e.g. During the 1990s the largest available float cells were in the ~100m^3 range whereas today cells as large as 700m^3+ are now available), so has the distance across the top of those float cells. In order to maintain minimum froth travel distances of no more than ~1 meter, radial launders should be considered in many applications.

With the increase in cell volumes, comes an increase in the amount of concentrate floating to the surface and into those launders. Care should be taken to ensure that the lip loading in those scenarios is optimal (Ideally between 1.0 – 1.5 t/m/hr). The addition of radial launders can be used to optimize the overall launder length for a given process scenario.

Another use of launders is in the launder design itself. Figure 2 shows an illustration of different types of radial launders that can be used to optimize the performance of different cell types. The traditional rounded radial launders (top half of illustration) are generally implemented on cells with outward radial froth flow patterns as occurs in a self-aspirating flotation cell. These launders are notably different from the other launder type shown by viewing the tip of the launder which is rounded and optimizes the recovery into the peripheral launders. This radial movement occurs because of the location of the rotor mechanism towards the top of the flotation cell which pushes the slurry and froth out toward the radial and peripheral launders.

The high efficiency radial launders (bottom half of illustration) are generally implemented on forced-air flotation cells that have different cell hydrodynamics than their self-aspirating counterpart.

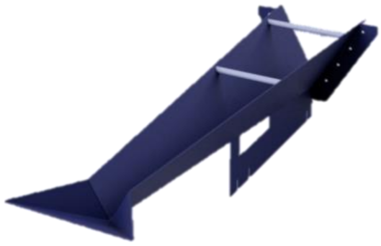

Figure 4: FLSmidth's High Efficiency Radial Launders

The primary circulation of the forced-air cell in the pulp phase has a flow pattern and movement towards the center of the cell as the pulp moves upward. Due to this inward flow, conical crowders are also generally implemented to influence the froth phase flow outward to the collection launders. The flared design of the launder acts as a mouth to ease the collection of the froth as it is pushed out by the central cone crowder.

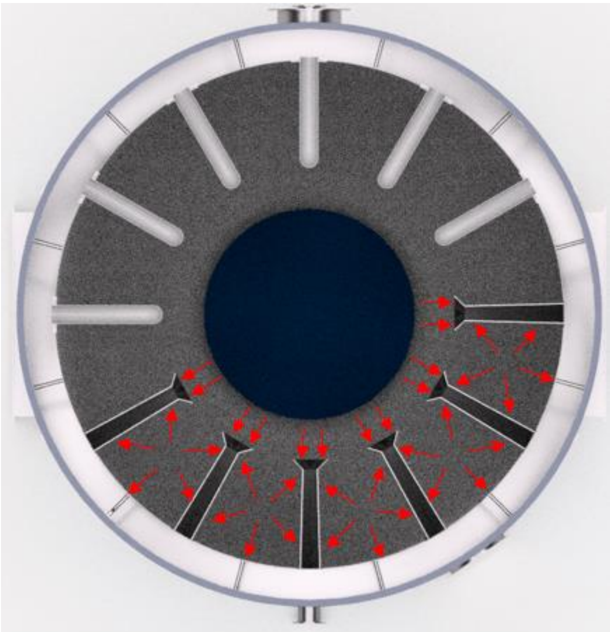

Figure 5: Froth Flow with High Efficiency Launders

3.2. Froth Crowders

The last piece in optimizing the froth recovery is the proper use of froth crowders. As mentioned previously, froth carry rates typically drop off significantly when the majority of the easy floating mineral has been removed from the cell. The concentration of attached mineral particles needs to be high enough in the froth to form a stable froth phase. Froth crowders can be utiliized to increase this mineral concentration by effectively reducing the surface area in the cell and crowding the remaining froth and minerals into a smaller area. This allows for a more stable, thicker froth that can be better controlled by the operator. The crowders also help push the froth into the launders and reduce the travel distance required by the froth to arrive at the launders, thus increasing the probability that those particles will be recovered. Two types of crowders that can be used are the central cone crowders and adjustable radial froth crowders.

3.2.1. ***Central Cone Crowders***

Central cone crowders have become standard in most larger flotation cells. Due to the increased size of cells and larger froth travel distances at the surface, the central crowder exists to reduce the overall surface area of the cell, and more importantly to reduce the froth travel distance at the top of the cell helping to push the froth toward the collection launders. These crowders can typically be slightly adjusted up or down during installation to optimize the area that is crowded.

Figure 6: Central Cone Crowder surrounded by High Efficiency Radial Launders.

3.2.2. ***Adjustable Radial Froth Crowders***

Adjustable Radial Froth Crowders are another useful tool for optimizing froth carry rates down a row of cells. When froth recovery is evaluated on a cell-by-cell basis down the row, it becomes clear that the optimization needs are different depending upon where the flotation cell is within the row. At the end of the row, most of the fast or readily floating minerals have already been removed. As this happens, the froth phase becomes thinner and less stable as the slurry moves down the row where upwards of 80% of the floatable concentrate is gone.

Adjustable radial froth crowders were designed for this purpose. By reducing the open cross-sectional area at the top of the cell, the crowders help facilitate a deeper and more stable froth bed, without reagent addition, while simultaneously reducing the froth travel distance to the nearest launder. The depth that the crowders are placed in the cell can easily be adjusted up or down. If more crowding is required, they can be lowered. If less is required, they can be raised. This allows the froth carry rate to be optimized for each individual cell down the row.

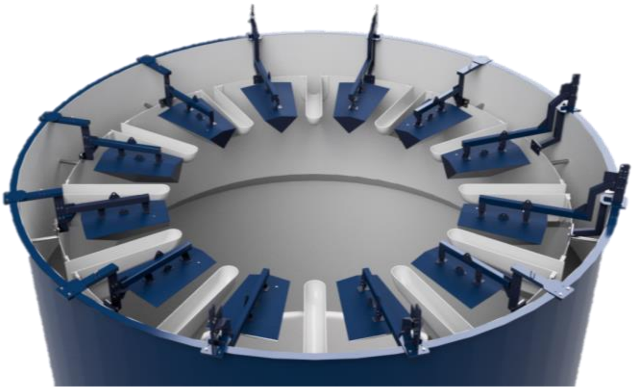

Figure 7: FLSmidth's Adjustable Radial Froth Crowders.

4. Example of Where Adjustable Radial Froth Crowders Can be Implemented.

The following table from a study done on a copper concentrator shows the corresponding weight pulls and recoveries collected down a row in a rougher circuit along with the corresponding calculated froth carry rates. The first 2-3 cells of the row is where the majority of the froth is collected and where the highest amount of surface area is needed in order to collect as much froth as possible coming to the top of the cell. Then, there is a much lower amount of concentrate down the rest of the row.

FLSmidth - Flotation Results

1 Row of (6) $600m^3$ Cells

Individual Results								
Cells	Ret. Time	Solids	Solids	Indvidual Grade, %		Distribution, %		Carry Rate
	min	tph	Wt Pull, %	Cu	Mo	Cu	Mo	tph/m^2
Cell 1 Feed		2750.0	100.00	0.320	0.0200	100.0	100.0	
Cell 1 Conc	4.4	63.8	2.32	8.12	0.442	58.8	51.2	1.16
Cell 1 Tails		2686.2	97.68	0.135	0.0100	41.2	48.8	
Cell 2 Conc	4.5	32.5	1.18	6.24	0.346	23.1	20.5	0.59
Cell 2 Tails		2653.7	96.50	0.060	0.0059	18.1	28.3	
Cell 3 Conc	4.6	12.6	0.46	3.32	0.219	4.7	5.0	0.23
Cell 3 Tails		2641.1	96.04	0.051	0.0054	15.4	25.8	
Cell 4 Conc	4.6	7.6	0.28	2.24	0.128	1.9	1.8	0.14
Cell 4 Tails		2633.6	95.77	0.045	0.0050	13.4	24.0	
Cell 5 Conc	4.6	6.8	0.25	1.58	0.091	1.2	1.1	0.12
Cell 5 Tails		2627.0	95.53	0.041	0.0048	12.3	22.9	
Cell 6 Conc	4.6	6.6	0.24	1.33	0.078	1.0	0.9	0.12
Cell 6 Tails		2620.2	95.28	0.038	0.0046	11.2	22.0	

Table 1: Row Performance of Cu Ro./Scav. Circuit

As was mentioned previously, recommended carry rates for rougher/scavenger circuits range from ~0.3 – 1.5 tph/m2. When this number drops below ~0.3-0.2, the froth will be sparse and unstable resulting in decreased froth recovery. In order to optimize this situation, there are two options: 1. Pull more material into the concentrate (this is usually not feasible, because most of the floatable material has already been collected so there is a limit in the amount of floatable material available spread over the surface of the cell.) 2. Reduce the surface area of the corresponding float cell in an effort to "squeeze" the froth into a smaller cross sectional area and shorten the froth travel distance. This helps increase the concentration of minerals present in a given surface area which gives the operator the ability to better control the surface and depth of the froth zone. The result is better froth recovery and/or grade reporting to the concentrate stream. The last three cells have very low carry rates due to the small amount of flotable mineral present at this stage in the circuit.

Reducing the surface area with adjustable radial froth crowders is the best option to achieve better performance. Doing so will shift the grade recovery curve. Through the combination of Adjustable Radial Froth Crowders and radial launders, the froth travel distance is reduced, mass pull velocity increased, and an overall increase in recovery is achieved. In these instances, the emphasis is to maintain froth depth and increase mass pull through the circuit. In most cases, a shift in recovery of more than 1% is expected.

N. Conclusions

In many mineral processing concentrators losses occurring from flotation cells are commonly between 1% and 5%, reaching even higher for coarse particle flotation. Often, the root cause of these losses is an inability to control the froth phase throughout the flotation circuit.

The answer to effective management of froth in flotation cells includes proper use of radial launders and the use of adjustable radial froth crowders. Radial launders and adjustable radial froth crowders provide the following key benefits to existing flotation circuits:

- Minimize froth drop back by optimizing froth travel distances.
- Improve overall process by providing better froth phase stability.
- Improve metallurgical performance by enabling froth depth control

Radial launders and adjustable radial froth crowders are easy to install, low risk options that will help optimize froth recovery in any flotation circuit.

References

Mining Chemicals Handbook, Cytec (Solvay) v. 2010 p. 99-100.