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Developing a Relationship between Ore Feed Grade and Flotation Performance †

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Abstract: Although topical research, the study of flotation systems remains complex, multifaceted and water intensive. Numerous physical and chemical factors are involved in the recovery of valuable minerals by flotation. While the chemistry of the system can be manipulated to improve the performance, the system is limited by the mineralogy of the incoming ore and the quality of the process water, which in most cases is not controlled. Recycling of onsite process water has become a norm for many operations; this recycling changes the water quality over time and may compromise the flotation process. The current study seeks to understand the impact of ore feed grade on froth stability, entrainment, and flotation performance under varying water qualities. The overarching aim is the development of a relationship through which the flotation performance may be predicted if the ore feed grade and water quality are known.

Keywords: froth flotation; froth stability; ionic strength; water recycling; flotation performance

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1. Introduction

Mining operations cannot operate without continuous access to water, the majority of which is utilized by mineral processing and dust suppression. The need to find alternative sources of water that meet operational demands has forced many mining operations to recycle onsite process water. This recycling may be a key engineering design; however, it may compromise the flotation process and the efficiency of the flotation performance. A fundamental understanding of mineral processing is thus paramount to maximize the recovery of valuable minerals.

2. Mineralogy

The mineralogy of an ore determines its flotation performance, thereby making the mineralogy of the incoming ore paramount for achieving high process performance and concentrates. Different ores bear different minerals and thus behave differently in the presence of chemical reactants; making it difficult to isolate and quantify individual reagent interactions with minerals in the ore [1]. Although limited by surface liberation and particle size; a synthetic ore allows for the isolation of distinct mineral behavior and can thus be used for the purpose of investigating the impact of the ore feed grade on flotation performance under varying water qualities.

3. Froth Flotation

Froth flotation is a physico-chemical separation process extensively used in mineral processing for separating minerals to concentrate them for economic smelting. The process utilizes the differences in surface properties of minerals to selectively separate valuable minerals from unwanted gangue [2].

Chemical reagents are added to a milled ore slurry to facilitate separation and enhance the difference in hydrophobicity between unwanted gangue and valuable minerals [3–6]. A typical reagent suite consists of collectors, depressants, frothers and sometimes activators [7,8].

A holistic understanding is essential to evaluate flotation reagent interactions both in the pulp phase and froth phase, as reagents may also interact with one another, in addition to their primary roles in the flotation process [9].

The manipulation of these reagents can improve performance; however, the system is limited by the mineralogy of the incoming ore as well as the quality of the process water, which in most cases is not controlled. The process utilizes a considerable amount of continuous water input, making water quality paramount for achieving high process performance and enrichment of valuables [10]. Recycling of onsite process water changes the water quality and may compromise the flotation process by affecting the rate of recovery, froth stability, mineral pulp and flotation performance. This adds complexity to the flotation process and its chemical reactants.

3. Froth Flotation Fundamentals

Flotation is modelled as a 2-stage process; first, the pulp stage, whereby mineral recovery occurs, and second, the froth phase, whereby concentrated valuable minerals are separated from the bulk [11]. Figure 1 shows an illustrative diagram of the flotation process and its components. Suspended mineral particles from the flotation pulp, report to the concentrate through two distinct mechanisms, namely, true flotation and entrainment [12,13]. True flotation is a selective process responsible for the collection of valuable minerals, while entrainment is a non-selective process responsible for the collection of both valuable and unwanted gangue minerals reporting to the froth phase [14,15]. True flotation is the dominant mechanism through which recovery of valuable minerals occurs.

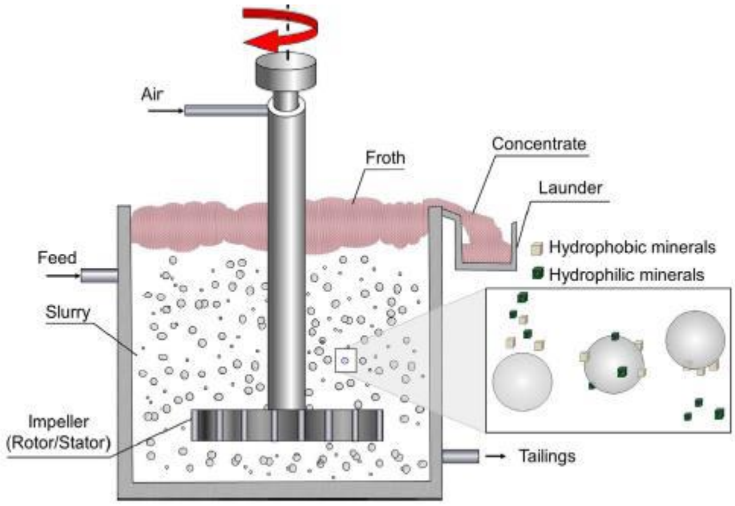

Figure 1. An illustration a flotation cell with its components [2].

4. Froth Stability Fundamentals

During the flotation process, air bubbles are generated and pass through the flotation pulp into the froth phase whereby they emerge surrounded by a thin liquid film. A plateau border with the liquid film develops when there is at least three bubbles clustering together [16]. Continuous clustering of bubbles results typically in the formation of polyhedral bubbles with films in between them; this is referred to as foam in the case of a two-phase system, and known as froth in the case of a three-phase system containing solid particles [16].

The froth phase provides an environment for separating hydrophobic valuables from unwanted gangue, and allow for the drainage of entrained material back into the flotation pulp [17]. For an optimum flotation performance, it is critical for flotation systems to exhibit an optimum froth stability [18].

Froth stability can be defined as the persistence of the froth or a measure of the froth's lifetime [17,19]. When the froth is unstable, bubbles continuously breakdown before collection, owing to liquid drainage from entrained material back into the flotation pulp; and when the froth is too stable, not enough liquid drainage occurs and as a result, high water and gangue recoveries are achieved. The froth phase may be characterised by the froth bulk and froth surface; froth surface stability is related to the bursting of bubbles into the atmosphere, while froth bulk stability is reflected by the size of bubbles on the froth surface.

5. Factors Affecting Froth Stability

Froth stability can be affected by several factors; mainly, particle properties, operational conditions and chemistry effects such as collectors, frothers and depressants [19]. Particle properties such as particle hydrophobicity, shape and size are of great importance to bubble particle attachment and significantly affect froth stability, and also have a substantial effect on the overall flotation performance, an extent which can be greater than the beneficial effects in the pulp phase [20]. These particle property effects have been shown to significantly affect froth stability with increasing distance from the pulp/froth interface, whereby the bubble films are thinner to allow for bridging to occur. Particle properties are said to have a greater influence on froth stability in comparison to operational factors (aeration rate, froth height and gas dispersion) and chemistry effects [20].

6. Chemistry Effects

Collectors impart particle hydrophobicity of minerals and can thus have a significant effect on froth stability, owing to the difference in the degree of hydrophobicity imparted onto the mineral particles [21]. Depressants suppress the floatability of naturally floatable hydrophobic gangue minerals and thus improve their selectivity. High depressant dosages reduce froth stability owing to the removal of naturally floatable gangue (such as talc), from the froth phase [9]. Frothers aid with bubble formation and froth stabilisation. They increase froth stability by reducing the surface tension of the gas-liquid interface [22]. An increase in frother dosage increases froth stability and results in higher solids and water recoveries. Furthermore, frothers aid with gas dispersion and reduce bubble coalescence in the pulp phase [22]. The amount of entrained material is related to the water recovered [23–25], the state of the suspended solid particles in the pulp phase and drainage in the froth phase. Entrainment is directly related to the amount of water recovered from the froth phase [26–28] (site), and as the ionic strength increases, the entrainability increases.

7. Froth Stability Measurements

Flotation recovery and concentrate grade are typically what is referred to when inferring flotation performance. Froth stability measurements aid the quantification and understanding of flotation performance.

Numerous methods have been proposed and used to measure froth stability, and these include; velocity of the froth, rate of bursting of the froth and the solids loaded onto air bubble lamellae [29]. Non-overflowing and overflowing systems can be used for assessing froth stability. Overflowing systems are preferred over non-overlying systems because they take into consideration continuous systems, which is what most industrial operations are [30].

Ore mineralogy effects on froth stability were assessed by comparing two different ores, UG2 and Iron ore [31], and dynamic forth stability was reported to increase exponentially with decreasing particle size as shown in Figure 2. This is consistent with literature findings [32], which reported an inverse relationship between particle size and froth stability. Figure 3 shows that for a given particle distribution, the dynamic froth stability decreases as the airflow rate increases [20]. Furthermore, similar to Figure 2, Figure 3 shows a decrease in dynamic froth stability as the feed particle size increases; thus implying that, increasing the milling time and generally producing finer feed increases the dynamic froth stability. Froth height variations with time at different aeration rates, illustrated these finding further [20].

Numerous studies have been conducted which relate the destabilizing effects of course particles and stabilizing effects of fine particles on froth stability [20,32,33].

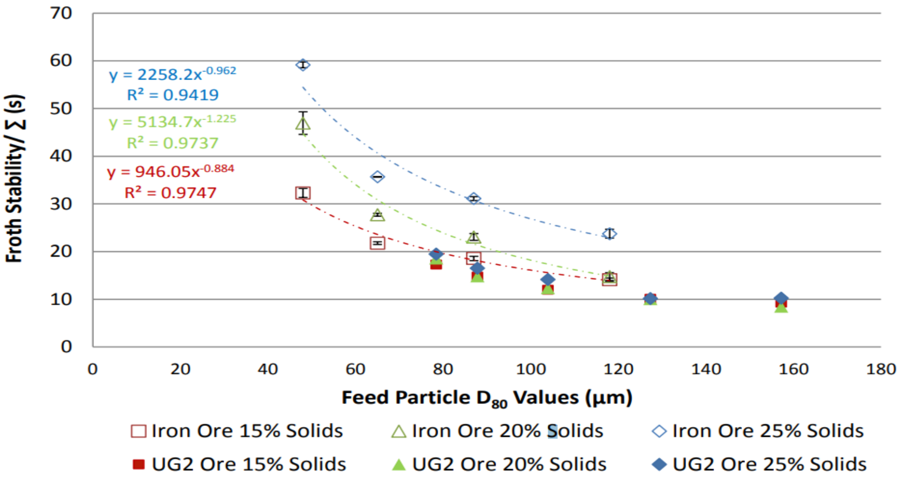

Figure 2. Dynamic froth stability as function of feed particle size for Iron ore and UG2 [31].

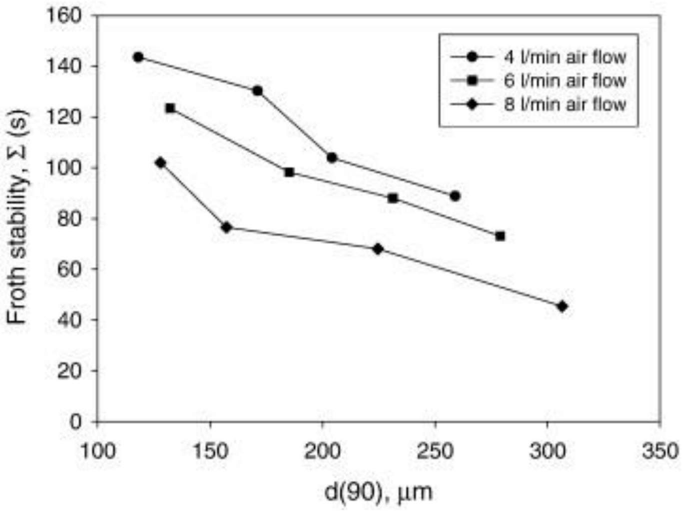

Figure 3. Dynamic froth stability variations as a function of d(90) particle size for different flow rates [20].

By using grade and desired mineral recovery as performance proxies, the overall flotation performance was assessed by plotting recovery as a function of feed particle size as shown in Figure 4 [31]. An increase in PGM grade was observed with increasing particle size, and a reduction in PGM recovery was observed with increase in froth height. Furthermore, a general increase in PGM recovery was observed with a decrease in feed particle size [31].

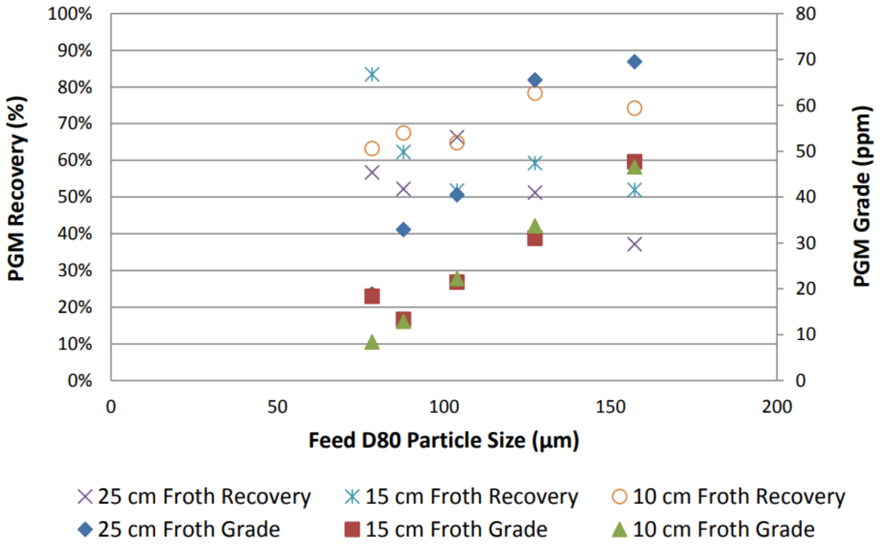

Figure 4. PGM recovery and grade variation as function of feed particle size for UG2 [31].

Increasing conditioning time of the collector causes a decrease in froth stability and solid concentrate, and water recovery. The amount of entrained material is related to the water recovered [23–25], drainage in the froth phase and the state of the solid particles suspended in the pulp phase. The degree of entrainment or entrainability can be measured using the recovery of the Non-Floating Gangue component in correlation to water, in ratio terms.

8. Future Work

Considering the discussed literature review and the ongoing research on froth flotation, the present-day study aims to investigate the impact of ore feed grade on froth stability, entrainment, and flotation performance under varying water qualities. The overarching aim is the development of a relationship through which flotation performance may be predicted if the ore feed grade and water quality are known.

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