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Evaluation of Critical Parameters for Wettability-Based Processes in Mineral Processing

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Abstract

This paper presents an evaluation of critical parameters for wettability-based processes such as flotation, shear flocculation, oil agglomeration and liquid–liquid extraction in mineral processing. 'The critical surface tension of wetting (γ_c)' value of minerals has crucial importance in these processes. Also, 'the critical solution surface tension for oil agglomeration ($\gamma_{c\text{-}a}$)' and 'the critical solution surface tension for liquid–liquid extraction ($\gamma_{c\text{-}e}$)' parameters, which are slightly higher than the γ_c value of the mineral, exist for achieving the oil agglomeration and liquid–liquid extraction techniques. In the case of three-phase systems composed of solid, liquid/medium and oil such as oil agglomeration and liquid–liquid extraction techniques, there is a second critical parameter based on the oil–liquid interfacial tension (γ_{OL}) which are 'the critical oil–liquid interfacial tension for oil agglomeration, $\gamma_{c\text{–}OL\text{–}a}$' and 'the critical oil–liquid interfacial tension for liquid–liquid extraction, $\gamma_{c\text{–}OL\text{–}e}$', respectively.

Keywords: Wettability, Flotation, Shear flocculation, Oil agglomeration, Liquid–Liquid extraction.

Cevher Hazırlamada Islanabilirliğe Dayanan İşlemler İçin Kritik Parametrelerin Değerlendirilmesi

Özet

Bu çalışmada, cevher hazırlamada ıslanabilirliğe dayanan işlemlerden olan flotasyon, makaslama flokülasyonu, yağ aglomerasyonu ve sıvı–sıvı ekstraksiyonu için kritik parametreler değerlendirilmiştir. Bu işlemlerde 'kritik ıslanma yüzey gerilimi (γ_c)' değeri oldukça önemlidir. Ayrıca, mineralin γ_c değerinden biraz yüksek olan 'yağ aglomerasyonu için kritik çözelti yüzey gerilimi ($\gamma_{c\text{-}a}$)' ve 'sıvı–sıvı ekstraksiyonu için kritik çözelti yüzey gerilimi ($\gamma_{c\text{-}e}$)' değerleri yağ aglomerasyonu ve sıvı–sıvı ekstraksiyonu tekniklerinin başarılı olabilmesini sağlayan parametrelerdir. Katı, sıvı/ortam ve yağdan oluşan üçlü faz sistemlerinin bulunduğu yağ aglomerasyonu ve sıvı–sıvı ekstraksiyonu yöntemlerinde, yağ–sıvı ara yüzey gerilimine (γ_{OL}) dayanan ikincil kritik parametreler ise sırasıyla 'yağ aglomerasyonu için kritik yağ–sıvı ara yüzey gerilimi, $\gamma_{c\text{–}OL\text{–}a}$' ve 'sıvı–sıvı ekstraksiyonu için kritik yağ–sıvı ara yüzey gerilimi, $\gamma_{c\text{–}OL\text{–}e}$'dir.

Anahtar Kelimeler: Islanabilirlik, Flotasyon, Makaslama flokülasyonu, Yağ aglomerasyonu, Sıvı-Sıvı ekstraksiyonu

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1. INTRODUCTION

In mineral processing, comminution is required to liberate the valuable minerals. However, fine particles produced during grinding process reduce the efficiency of the enrichment processes. Therefore, there is a considerable interest in developing process that could successfully handle such fine particles. Flotation, shear flocculation, oil agglomeration, liquid−liquid extraction methods are effective techniques among fine particle processing methods [1-7].

The selectivity in separation techniques is provided by physical, chemical and physicochemical differences between minerals. Under the influence of appropriate chemicals, the surfaces of some mineral particles can be chemically modified. The wettability of mineral surfaces controlled by the solution surface tension is known to be an important parameter which affects many technological processes [8].

The mineral processing operations given above are based on the wettability differences of mineral surfaces. Flotation method is the oldest technique among them. In this process, after treatment with reagents, such differences in surface properties between the minerals in the flotation pulp become obvious. Then, an air bubble must be skilful to attach itself to a particle and lift it to the water surface for flotation to take place. The mineral particles can sufficiently attach to the air bubbles if they are hydrophobic enough [9].

The other method known as shear flocculation also relies on the hydrophobicity of particles. Shear flocculation of hydrophobic particles is taken place when sufficient kinetic energy is provided mechanically [10,11]. Surfactants known as flotation collectors are often used to enable hydrophobization of mineral surfaces.

When the mineral surfaces are hydrophobic, oil used as bridging liquid preferably wets the mineral surfaces via spreading. Provided intense agitation distributes the oil into fine droplets and allows the hydrophobic particles to agglomerate form of oil-coated particles merged to other oil-coated particles. Acquired agglomerates can be separated from the hydrophilic particles by screening [2,12].

The liquid−liquid extraction is another method in the oil−assisted fine particle processing. Non-polar organic liquids are used as a second liquid and particles transfer to organic or water phase depend on their hydrophobicity [4].

The main purpose of this paper is to summarize the critical parameters which control wettability-based processes such as flotation, shear flocculation, oil agglomeration and liquid−liquid extraction in mineral processing.

2. BACKGROUND

The contact angle (θ) has been broadly used to specify the hydrophobicity or wettability degree of the particles in mineral processing theory and practice. It is a measure of surface hydrophobicity of solids so $\theta>0$ indicates that the surface has hydrophobic character. The wettability properties of solid or minerals are assessed quantitatively by a number of experimental and empirical techniques. One of these quantifying parameters mentioned above is the critical surface tension of wetting (γ_c) values to achieve selectivity in surface chemistry processes [13].

The γ_c parameter is determined by contact angle measurement, flotation, immersion time, bubble pickup, film flotation, automatic wetting balance, modified Hildebrand–Scott equation and shear flocculation methods [14−21]. The Zisman contact angle measurement technique and the flotation method are often used to determine the γ_c values of minerals among these experimental and empirical techniques [9,13,22,23].

In the Zisman contact angle method [14], cosines of measured contact angles are plotted against solution surface tension (γ_{LV}) and the intercept of this line at the x–axis (for cos θ=1 or $\theta = 0$) is γ_c. As seen from Figure 1, the liquid spreads on the solid (mineral) at $\gamma_c \geq \gamma_{LV}$, the liquid forms a contact angle ($\theta > 0$) at $\gamma_c < \gamma_{LV}$.

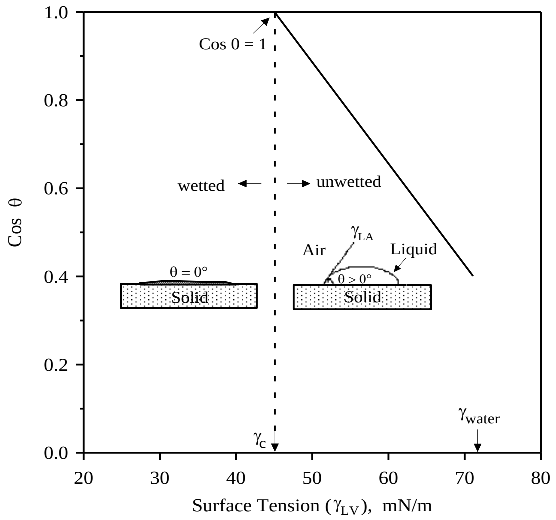

Figure 1. Schematic representation of the contact angle measurement method for the γ_c determination [14].

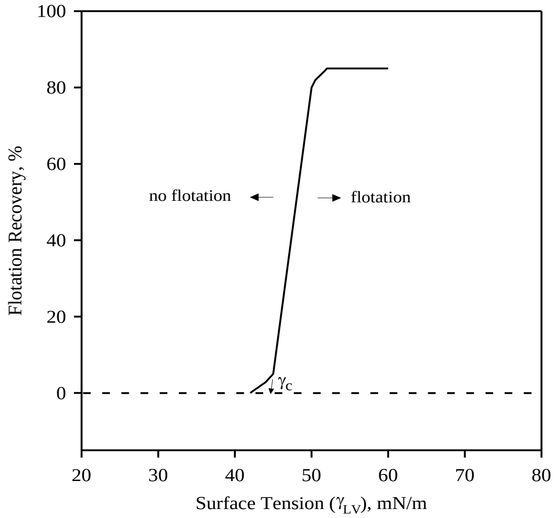

Figure 2. Schematic representation of the flotation method for the γ_c determination [15].

3. CRITICAL PARAMETERS FOR WETTABILITY-BASED PROCESSES

3.1. Flotation

Yarar and Kaoma [15] found that the flotation recovery of minerals decreases as decrease of the air–liquid interfacial tension of the liquids used as flotation medium. Based on this finding, the authors also proposed the flotation method to determine the critical surface tension of wetting (γ_c) of minerals. As seen in Fig. 2, the flotation method estimates the γ_c value of any mineral by plotting % flotation recovery versus solution surface tension (γ_{LV}) with the extrapolation of the linear part of the flotation recovery–γ_{LV} curve to the surface tension axis in order to obtain an intercept at % flotation recovery = 0.

3.2. Shear Flocculation

Similar to the flotation behaviour of minerals, the shear flocculation of the mineral suspension also decreases in tandem with the decrease of the surface tension of the liquids used. By using this property, the shear flocculation method as a new approach to determine the critical surface tension of wetting of minerals treated with surfactants was contributed by Ozkan [21]. This approach is presented in Figure 3 and no effective shear flocculation takes place at $\gamma_c \geq \gamma_{LV}$ while the effective shear flocculation of mineral suspension occurs at $\gamma_c < \gamma_{LV}$.

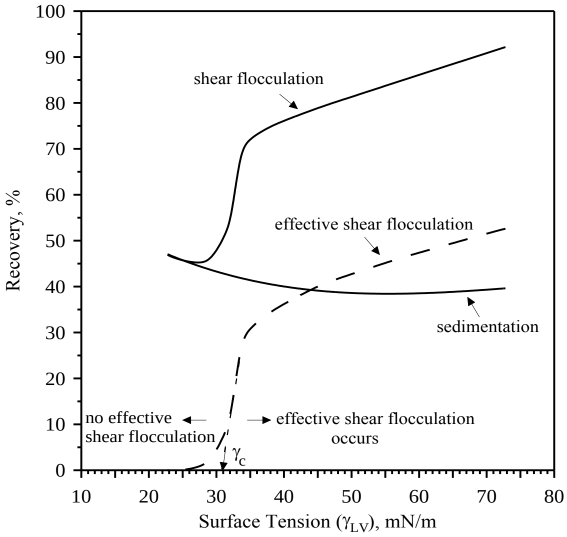

Figure 3. Schematic representation of the shear flocculation method for the γ_c determination [21].

3.2. Oil Agglomeration

Ozkan et al. [6] stated that a critical value of solution surface tension existed for achieving the oil agglomeration process. This critical value is slightly higher than the γ_c value of mineral. This solution surface tension value was defined as 'critical solution surface tension for oil agglomeration ($\gamma_{c\text{-}a}$)'. The effect of the solution surface tension for the oil agglomeration of a mineral is presented in Figure 4 and the oil agglomeration of mineral particles occurs when γ_{LV} is higher than $\gamma_{c\text{-}a}$ value.

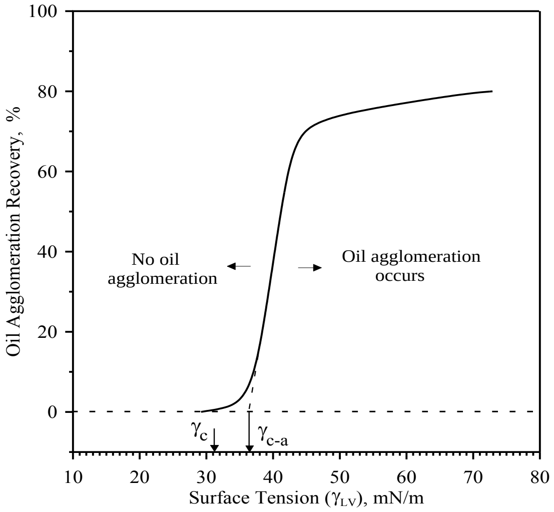

Figure 4. Schematic representation of the effect of solution surface tension on the oil agglomeration process [6].

The three-phase systems such as oil agglomeration and liquid–liquid extraction processes are composed of solid, liquid/medium and oil. Duzyol et al. [7] reported that the oil agglomeration process of minerals did not take place below a particular value of the oil–liquid interfacial tension. That is, there is also a second critical parameter for achieving the oil agglomeration of minerals. This critical value of the oil–liquid interfacial tension was defined as 'critical oil–liquid interfacial tension for oil agglomeration, $\gamma_{c\text{–}OL\text{–}a}$'. A schematic representation for the effect of oil–liquid interfacial tension (γ_{OL}) on the oil agglomeration process is given in Figure 5. As can be seen, while the oil agglomeration of mineral suspension occurs at $\gamma_{c\text{–}OL\text{–}a} < \gamma_{OL}$, no oil agglomeration takes place at $\gamma_{c\text{–}OL\text{–}a} \geq \gamma_{OL}$.

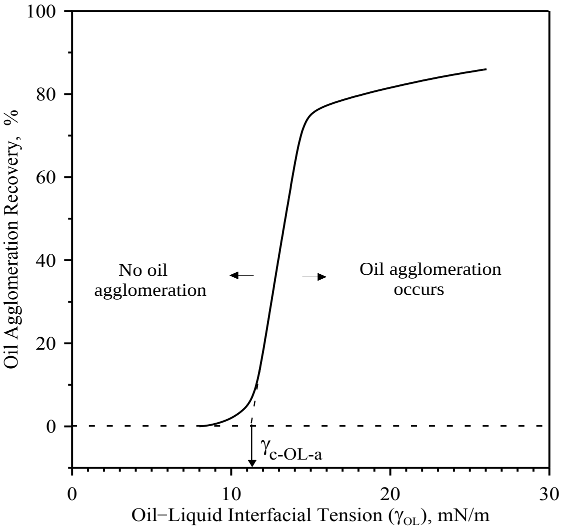

Figure 5. Schematic representation of the effect of the oil–liquid interfacial tension (γ_{OL}) on the oil agglomeration process [7].

3.3. Liquid−Liquid Extraction

The effect of the solution surface tension on the liquid–liquid extraction of minerals was studied by Ozkan and Duzyol [24]. As shown in Figure 6, the liquid–liquid extraction of mineral decreases with decreasing solution surface tension, and eventually the liquid–liquid extraction does not occur below a particular value of the solution surface tension. The solution surface tension value at which liquid–liquid extraction does not take place was called 'the critical solution surface tension for liquid–liquid extraction, $\gamma_{c\text{-}e}$'. As a result, the liquid–liquid extraction process of mineral is achieved when γ_{LV} is greater than $\gamma_{c\text{–}e}$ value.

Duzyol et al. [7] also introduced the effect of oil–liquid interfacial tension on the liquid–liquid extraction of a mineral. The liquid–liquid extraction recovery of minerals also decreases with the decrease in the oil–liquid interfacial tension and does not occur below a particular value of the oil–liquid interfacial tension (γ_{OL}). That is, the minerals at oil–liquid interfacial tensions below this critical value remain in the water phase instead of transfer to the oil phase. This second critical value for liquid–liquid extraction process was also defined as 'critical oil–liquid interfacial tension for liquid–liquid extraction, γ_{c-OL-e}'. Similar to the agglomeration process, for a successful liquid–liquid extraction of a mineral, as illustrated in Figure 7, the oil–liquid interfacial tensions (γ_{OL}) must be higher than the γ_{c-OL-e} value.

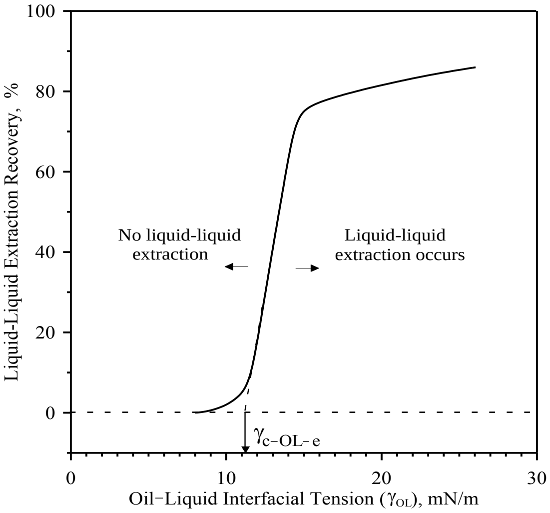

Figure 7. Schematic representation of the effect of the oil–liquid interfacial tension (γ_{OL}) on the liquid–liquid extraction process [7].

4. CONCLUSIONS

In the flotation and shear flocculation processes, 'the critical surface tension of wetting (γ_c)' value of minerals has a crucial importance. That is, the success of these processes decrease as decrease of the air–liquid interfacial tension of the liquids used as medium. Eventually, the flotation and shear flocculation of minerals do not occur at the air–liquid interfacial tensions below 'the critical surface tension of wetting (γ_c)' value of the mineral.

The critical surface tension of wetting (γ_c) value of minerals also is an important parameter in the oil agglomeration and liquid–liquid extraction techniques. However, other critical values of solution surface tension (γ_{LV}) exist for achieving the oil agglomeration and liquid–liquid extraction processes and these critical values are relatively higher than the γ_c value of mineral because the particle surfaces require a lower wettability degree for these processes. These critical solution surface tension values are known as 'the critical solution surface tension for oil agglomeration ($\gamma_{c\text{-}a}$)' and 'the critical solution surface tension for liquid–liquid extraction ($\gamma_{c\text{-}e}$)'. Duzyol et al. [7] also indicated that although the oil agglomeration and the liquid–liquid extraction are different processes, these oil-assisted techniques are fundamentally the similar processes in terms of their occurrence mechanism. Consequently, it can be accepted that the $\gamma_{c\text{-}a}$ and the $\gamma_{c\text{-}e}$ parameters are essentially the same. However, a single parameter is not used to describe both processes, because they are, in practice, two different processes.

There is a second critical parameter for the three-phase systems composed of solid, liquid/medium and oil. The oil agglomeration and liquid–liquid extraction techniques also do not take place below a particular value of the oil–liquid interfacial tension and these critical values of the oil–liquid interfacial tension are called 'the critical oil–liquid interfacial tension for oil agglomeration, γ_{c-OL-a}' and 'the critical oil–liquid interfacial tension for liquid–liquid extraction, γ_{c-OL-e}', respectively. Also, it can be accepted that the γ_{c-OL-a} and the γ_{c-OL-e} parameters are essentially the same due to the same reason mentioned above [7].

As a summarize, for a successful process of flotation, shear flocculation, oil agglomeration and liquid–liquid extraction of a mineral, the solution surface tension (γ_{LV}) value must be higher than the γ_c value of the mineral. Also, the solution surface tension value for oil agglomeration and liquid–liquid extraction must also be greater than the $\gamma_{c\text{-}a}$ and the $\gamma_{c\text{-}e}$ values which are slightly higher than the γ_c value of the mineral. In addition, the oil–

liquid interfacial tension (γ_{OL}) value for successful oil agglomeration and liquid–liquid extraction of any mineral must be greater than the γ_{c-OL-a} and the γ_{c-OL-e} values, respectively.

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