



A review of the role of wetting and spreading phenomena on the flotation practice



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ABSTRACT

Wetting and spreading phenomena are the most important parameters for understanding of froth flotation practice. The wetting and spreading of fluids on the solid surface should be considered in the high efficiency flotation process. These phenomena involve surface tension forces, contact line dynamics, surface roughness and heterogeneity, contact angles, bubble–particle interactions and other factors. This review highlights the various concepts of contact angles and well-known equations in this respect and compares these equations. Based on this review, flotation selectivity and efficiency are highly dependent on solid–liquid contact angles and collision, collection, attachment, and stability efficiency could be predicted by wetting and spreading roles. In order to control flotation performance, efforts should be made to determine wetting characteristic of the flotation process. It is imperative that an improved understanding of wetting and spreading phenomena in the phase's interfaces will provide an improved and efficient flotation practice. It is proposed that future research should focus on the scientific and engineering aspect of wetting and spreading phenomena on flotation and on the development of a method to enhance flotation performance by controlling these phenomena.

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1. Introduction

Wetting, which is a subject for studying the displacement of two immiscible fluids (generally, one fluid is gas/vapor, another is liquid) on a solid surface, plays an important role in many theoretical investigations and engineering applications. Wetting phenomena are widespread in nature and occur whenever a surface is exposed to an environment [1]. They play an important role in many industrial processes, such as polymer processing, flotation of mineral, printing, oil recovery, lubrication, liquid coating, printing, drainage of water from highways, spray quenching and flow of the thin film [2,3,55]. Wetting phenomena are an area where chemistry, physics, and engineering intersect. Surface chemistry is of key importance in determining wetting behavior, and much research has been devoted to modifying the surface chemistry of various solids in order to obtain specific wetting properties [55]. To completely understand the wetting and spreading interactions, chemistry, physics, and engineering field of studies should be meticulously taken into account specifically in which surface chemistry, forces, and molecular interactions play a key role on wetting occurrence [2]. In addition to the surface chemistry, surface forces such as van der Waals or

electrostatic forces are paramount for determining whether or not a fluid will wet a given surface.

Wettability studies require the measurement of contact angles as a representative of the degree of wetting when a solid and a liquid interact. Small contact angles ($<90^\circ$) correspond to high wettability, while large contact angles ($>90^\circ$) correspond to low wettability [3]. The flotation process is the most effective beneficiation process and it has been widely used, for over a century, to quickly and efficiently separate valuable minerals from gangue minerals, based on the differences in their natural or induced hydrophobicity or wettability. Flotation process is controlled by wetting and spreading phenomena. The mechanism of particle–bubble interactions is based on wetting and spreading phenomena and this process controls flotation selectivity and collection efficiency where kinetics and energetics are inextricably mixed during a dynamic process [4]. Research into froth flotation has been concerned mainly with the establishment of a quantitative like between surface wettability and floatability. Recent investigations have made a great attempt to integrate wetting behavior into a model simplifying the relation between wetting parameters by contribution of mathematical equations. Chemical properties (heterogeneity) and physical properties (surface roughness, shape, and particle size) equally influence wetting behaviors [5].

With due regard to the importance of wetting and spreading phenomena in successful flotation, a review of the literature regarding the key factors involved in the application of these phenomena in the

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flotation process is presented. This review, first begin with fundamental science description of wetting, contact angle and spreading phenomena. Next the problems affecting real contact angle and wettability which is related to surface characteristics are described.

Finally, the wetting characteristics of mineral surfaces and influence of factors on contact angle measurement and mineral surface hydrophobicity such as surface roughness, heterogeneity, and shape and particle size are discussed.

2. Fundamental description of wetting and spreading

Hydrophobicity and hydrophilicity are important surface properties of materials. The contact angle is a very common measure of the hydrophobicity of a solid surface and is an important parameter in the wet processing of a material such as froth flotation. Several methods have been proposed to measure the value of contact angle which is fundamental to understand when hydrophobicity of solid surfaces is taken into account. Three well-known measurements of contact angle have been developed until now which are mentioned below [5].

2.1. The Young equation (surface tension and contact angle)

The first relationship between contact angle and surface tensions has been presented by Young [5]. In principle, the contact angle of an air bubble on a solid surface in an aqueous solution, as shown in Fig. 1.a, is determined by the mechanical equilibrium under the action of three interfacial tensions. The contact angle determined by balancing the surface tension forces is known as Young's contact angle, θ_Y , and the relationship describing the balance of surface forces is known as Young's equation.

The interface where solid, liquid, and air co-exist is referred to as the "three phase contact line". Fig. 2 shows that a small contact angle is observed when the liquid spreads on the surface, while a large contact angle is observed when the liquid beads on the surface. If θ reaches zero, liquid will completely wet the substrate and if $\theta \ll 90$ the partial wetting can be expected and the fluid will spread over a large area on the surface. On the other hand for $\theta \gg 90$ liquid and solid substrates tend to decrease the contact line during surface interactions and the fluid will minimize its contact with the surface and form a compact liquid droplet [6]. For super hydrophobic surfaces, water contact angles are usually greater than 150° , showing almost no contact between the liquid drop and the surface, which can only be achieved through the manipulation of surface roughness, texture, and porosity. Through increasing the temperature this hydrophobicity (examined by the

Raman Spectral Imaging method) will increase showing a large contact angle [7].

Skrdla [8] empirically proposed the equation of 'Equation of State' for interfacial tension describing another relationship between interfacial tensions and contact angles as:

$$\gamma_{sl} = \gamma_{lv} + \gamma_{sv} - 2(\gamma_{lv}\gamma_{sv})^{0.5} \exp(-\beta(\gamma_{lv} - \gamma_{sv})^2) \quad (1)$$

By applying Helmholtz and Gibbs free energy the empirical relation for β is obtained:

$$\beta = \frac{\psi}{3[(\gamma_{lv})^2 - (\gamma_{sv})^2]} \quad (2)$$

where

$$\psi = 0.25[1 - \cos(\theta)]^2[2 + \cos(\theta)]. \quad (3)$$

2.2. The Wenzel equation

On a rough surface (Fig. 1.c), the apparent contact angle is related to the ideal contact angle according to the Wenzel equation. This modification is required when the drop size is sufficiently large compared with the roughness scale, and if the liquid completely penetrates into the roughness grooves on the solid surfaces. The thermodynamic equilibrium contact angles on rough surfaces of solids can be explained by the Wenzel equation [9]. The basic assumption in Wenzel's equation is based on liquid movement into the surface roughness. On the contrary, the liquid can also be completely lifted up by the roughness surface features to give rise to a composite surface including solid-liquid and liquid-gas surfaces. If ($\theta_{app} < \theta$ and $\theta < 90$), wettability is improved by roughness for hydrophilic surfaces but if ($\theta_{app} > \theta$ and $\theta > 90$) it gets worse for hydrophobic surfaces. Based on the Wenzel theory, it is implicitly assumed that the surface features of the substrate are insignificant compared to the drop dimensions and that their geometry is of no consequence as long as it does not affect the surface area. If this assumption is ignored, the use of the Wenzel equation may lead to incorrect conclusions and error on contact angles.

2.3. The Cassie equation

Surface heterogeneity is justified after Cassie proposed a method to imply different surface chemistry (Table 1). In his equation f_1 is the fractional area of the surface with contact angle θ_1 , f_2 is the fractional area of

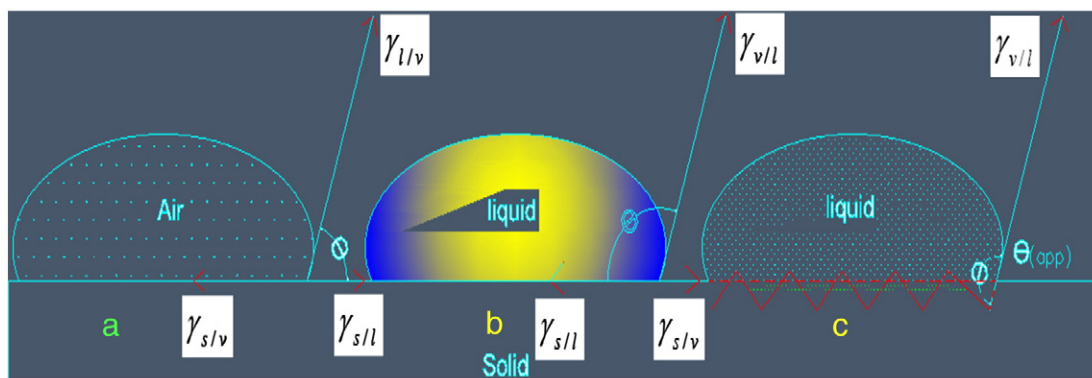


Fig. 1. Contact angle for different cases and their relationships with interfacial tensions according to the Young theory (figures a and b). Figure c states the Wenzel theory based on the surface roughness.

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