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Characterization of the interactions within fine particle mixtures in highly concentrated suspensions for advanced particle processing

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ABSTRACT

This paper aims to summarize recent investigations into the dispersion of fine particles, and the characterization of their interactions, in concentrated suspensions. This summary will provide a better understanding of the current status of this research, and will provide useful feedback for advanced particle processing. Such processes include the fabrication of functional nanostructures and the sustainable beneficiation of complex ores. For example, there has been increasing demand for complex ore utilization due to the noticeable decrease in the accessibility of high grade and easily extractable ores. In order to maintain the sustainable use of mineral resources, the effective beneficiation of complex ores is urgently required. It can be successfully achieved only with selective particle/mineral dispersion/liberation and the assistance of mineralogical and particle characterization.

Contents

1. Introduction

This paper aims to summarize the challenges and methods for dispersion and characterization of fine particle mixtures in highly concentrated suspensions to enhance particle processing. Such processes include the fabrication of functional nanostructures (e.g. electrorheological fluids) and the sustainable mineral beneficiation of complex ores which are often composed of finely disseminated valuable elements (e.g. Au, Ni, and rare earth elements). In mineral processing, as an example, proper dispersion/liberation of fine particles plays a key role in achieving selective enrichment of valuable minerals.

Dispersion of fine particles is, however, a challenging problem. The first difficulty is to achieve long-term stability of particle dispersions,

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avoiding re-coagulation after physical or chemical treatment. Conventional chemical/physical methods often encounter the problems of re-coagulation in highly concentrated suspensions [e.g. 1,2] which are commonly treated in plant operations. The cause of this coagulation can be an increase in particle–particle interactions as suspension concentration increases. Fig. 1 illustrates the effect of higher solid concentrations on the shear yield stress [3], a good indicator of the degree of particle interactions which drive coagulation. The relevant research on suspension rheology will be further discussed in Section 4.3. The second difficulty is to selectively disperse/liberate fine particles along grain/material boundaries. Conventional grinding and dispersion methods employ non-selective compressive forces to break/disperse the particles. On the other hand, electrical disintegration (discussed in Section 3.2) applies tensile forces which can selectively disperse/grind particles along their grain boundaries. This paper will introduce a new method of applying an electric field to disperse fine particles in concentrated suspensions, based on the results of our previous studies [4,5] which demonstrated effective particle dispersion using applied electric fields.

In addition, the challenge and current status of the characterization of concentrated suspensions will be discussed, since the success of particle dispersion can only be properly assessed by the application of the appropriate characterization methods which have been rarely studied in the past—there have been very few characterization studies of particle–particle interactions in mixed, highly concentrated suspensions. Particle processing, on the other hand, seeks to use the highest possible concentrations to minimize operational cost. The second half of this paper reviews and highlights the importance of characterization methods for mixed particle systems in concentrated suspensions in relation to industrial processes, especially mineral processing.

Thus, the specific aims of this paper are:

- *To review the current status-quo and new methods to disperse/liberate fine particles in concentrated suspensions;*
- *To review particle characterization methods applicable to the analysis of particle interactions in concentrated suspensions.*

The details of each aim will be explained more in the following sections.

2. Theoretical considerations in particle–particle interaction in concentrated suspensions

2.1. Applicability and limitation of DLVO theory

DLVO theory is one of the best-known theories for describing particle–particle interactions with the summation of the van der Waals potential and electrostatic potential [6,7]. If the total potential is high and positive (>15 kT), particles repel each other. On the other hand, if the total potential is negative, or a small positive value, particles attract each other. This is a straight forward theory which can explain particle coagulation/dispersion in many different colloidal systems [e.g. 8,9].

2.1.1. (Zeta potential)^2 vs. yield stress plot

In order to test the applicability of DLVO theory to a particular system, rheological measurements are often made, and the shear yield stress (τ_B) is plotted as a function of the square of the zeta potential (ζ). If DLVO interactions govern particle–particle interactions, there should be a linear correlation between those two values [10]:

$$\tau_B = \tau_{B(\max)} - k\zeta^2 \tag{1}$$

where $\tau_{B(\max)}$ is the maximum shear yield stress value at the isoelectric point, and k is a constant.

This approach has been widely accepted and extensively used to study particle–particle interactions in advanced particle processing [e.g. 11], though discrepancies can arise (see Section 4.3 on suspension rheology).

2.1.2. Particle–particle distance in concentrated suspensions.

When the solid concentration increases, the surface distance between two particles drastically decreases. In such environments, particles can coagulate even under dispersive chemical conditions (e.g. high surface charge by increasing suspension pH). For example, an increase in solid concentration from 10 to 40 vol.% decreases the surface distance from 30 to 4 nm in the case of 100 nm particles [12]. In such cases, the average particle distance can be closer than the potential barrier created, and coagulation can occur. Although this argument is commonly used, the experimental validation has rarely been carried out; so, such validation must be performed to determine to what extent DLVO theory applies in concentrated suspensions. This kind of investigation can potentially provide valuable information to the advanced particle processing industry.

3. Challenges in particle dispersion/liberation in concentrated suspensions

3.1. International research progress in this field

In this paper, our interests are particles dispersed in a liquid (mainly water), relevant for many industrial particle processing operations. Recently, in-situ synthesis of dispersive nanoparticles has been developed [13,14]. However, there are limitations in the potential combinations of dispersive surfactant molecules and liquids which can be used. In other words, the type of dispersive nanoparticles synthesized by these methods is limited to specific conditions. In this paper, dispersion of fine particles synthesized or generated from natural ores, mainly hydrophilic oxide particles, is discussed. Such oxide particles are processed in plants in diverse fields from pharmaceuticals to natural ore beneficiation by standard separation methods, such as froth flotation, where a surfactant (collector) selectively adsorbs onto a target mineral particle to change its hydrophobicity. Air bubbles injected into the cell attach to the hydrophobic particles due mainly to the hydrophobic interaction, and the particle–bubble complexes rise to the air–water interface for collection [15]. This method relies on good dispersion of the different mineral particles from a ground ore in order to have selective attachment of the surfactant onto the target mineral particles. In other words, selective dispersion/liberation is a key to achieving the

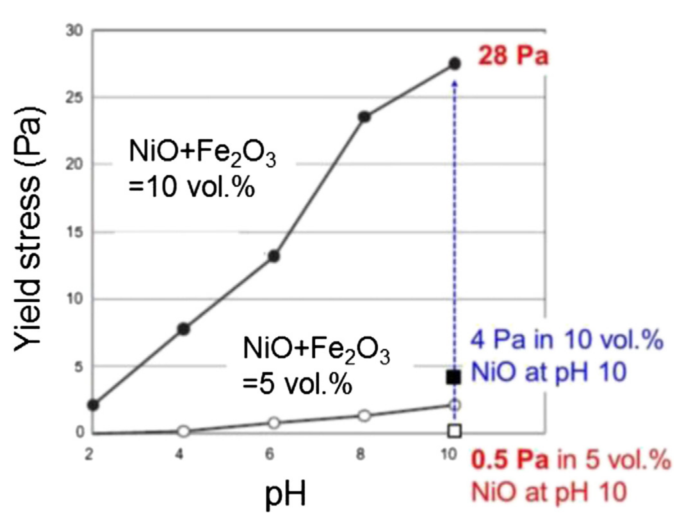

Fig. 1. Shear yield stress of nickel oxide-hematite suspension as a function of solid concentration and pH. Volume % of solid = 5, 10 [modified from ref. 3].

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