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Utilisation of ultrasonic treatment for upgrading of hematitic/goethitic iron ore fines

E. Donskoi [a,*], A.F. Collings [b,1], A. Poliakov [a], W.J. Bruckard [c]

[a] CSIRO Process Science and Engineering, PO Box 883, Kenmore, QLD 4069, Australia
[b] CSIRO Materials Science and Engineering
[c] CSIRO Process Science and Engineering, Box 312, Clayton South, VIC 3169, Australia

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ABSTRACT

Ultrasonic waves in pulps containing iron ore fines can start, or significantly intensify, particle cleaning, de-agglomeration or disintegration. Some softer minerals, often gangue minerals with lower iron contents such as kaolinite or ochreous goethite, disintegrate several orders of magnitude faster than the valuable iron-bearing minerals such as magnetite or hematite. This facilitates selective disintegration of the gangue minerals leaving the valuable minerals mostly unchanged.

A set of experiments involving ultrasonic treatment of four Australian iron ore fine samples was undertaken using three different ultrasonic experimental setups. The effect of ultrasound duration, power and pulp density on the recoveries and grades of iron, alumina and silica was studied.

The results showed that for hematitic/goethitic ores, the application of ultrasound enabled soft material of relatively low iron grade to de-agglomerate from the larger size fractions and report to the ultrafine size fractions. Modelled de-sliming of the ultrasonically treated ores showed that de-sliming following ultrasonic treatment could significantly improve the product iron grade, while de-sliming with a finer cut size could also improve the iron recovery compared with de-sliming identical ore that had not been pre-treated with ultrasound. It has been shown mathematically that in some scenarios it may be possible to simultaneously increase the iron grade and iron recovery in the de-slimed product if the ore has been treated with ultrasound before de-sliming.

1. Introduction

It is well known that ultrasonic waves in water or a pulp can initiate, or significantly intensify, different physicochemical phenomena such as polymerisation and depolymerisation, emulsification and coagulation, surface cleaning, reduction and oxidation, activation, and even mineral disintegration. Vibrations in the water/pulp create a series of rarefactions and compressions and the nucleation of microbubbles can be initiated when there is a pressure drop within the rarefaction areas. There are two major mechanisms proposed for microbubble nucleation: liquid gasification, when the boiling point of the liquid is exceeded, and the release of dissolved gases (gaseous cavitations). The microbubbles collapse when their diameter exceeds a critical value, and such collapses can result in shock waves which can generate very localised high pressures (up to 5000 atm) and temperatures (up to 5000 K) (Ross, 1976; Mason and Lorimer, 1991; Gogate and Pandit, 2001; Didenko and Suslick, 2002; Flannigan and Suslick, 2005). These phenomena can significantly affect the physicochemical properties and reactions of liquid and solid phases in a pulp.

The utilisation of ultrasonic treatments to enhance the beneficiation of different minerals and coals has been extensively studied (Warren, 1992; Tao and Parekh, 2000; Farmer et al., 2000). It would seem reasonable to expect that ultrasonics may be useful in one or more of the different stages of iron ore beneficiation such as flotation, magnetic separation, or classification (hydrocycloning) to provide improvements in iron recovery and grade. Franko and Klima (2002) have reported that ultrasound treatment helps separate ultra fines attached to larger particles in iron ore beneficiation processes. In ground iron ores, these ultra fine size fractions generally have lower iron content and greater alumina and silica contents than the larger size fractions (Donskoi et al., 2008a, 2006a,b), thus providing opportunities for ore upgrading.

Donskoi et al. (2006b) have shown that application of ultrasound/stirring can have a significant effect on iron ore fines by liberating lower grade physically entrained ultrafines from larger size fractions, which increases the grade of the product after de-sliming. Later, utilising optical image analysis and automatic iron ore texture classification (Donskoi et al., 2010a, 2008b, 2007a), it has been shown (Donskoi et al., 2007b) that for the larger iron ore size fractions the mass proportion of textural classes containing higher amounts of ochreous goethite and kaolinite had significantly decreased after ultrasonic treatment. In contrast, the proportion of texture classes in which hematite and vitreous goethite were the major minerals had

* Corresponding author. Tel.: +61 7 3327 4158; fax: +61 7 3327 4682.
E-mail address: Eugene.Donskoi@csiro.au (E. Donskoi).
[1] Deceased.

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increased. The interpretation was (Donskoi et al., 2007b) that softer components of the ore, such as ochreous goethite, or aluminosilicate phases, such as kaolinite, significantly disintegrate when exposed to ultrasound treatment. Thus, it was shown that these two sub-processes of de-agglomeration and disintegration of the softer components of particles occurring during ultrasonic treatment could lead to improved product quality following hydrocyclone de-sliming. Pandey et al. (2010) also showed that ultrasound treatment followed by de-sliming could significantly reduce alumina, silica and phosphorous in two Indian iron ores. In their experiments, the optimal time of treatment was 5 min, after which the level of alumina and silica in the de-slimed product started increasing again. Their observation was explained by a so-called "fusion" effect. However, iron recovery data was not analysed, so there is also a strong possibility that after 5 min of treatment soft hematitic structures started to be disintegrated, which resulted in a decrease in the iron grade. The experiments by Pandey et al. (2010) were performed in an ultrasonic tank without stirring, and the treated ore settled on the bottom of the tank. The importance of ore suspension during sonication has not been shown. Our current research shows that the complete suspension of iron ore in the slurry can significantly improve the ultrasonic effect and can protect removed low grade material from "fusion" effects. The mineral composition of the ore was not discussed by Pandey et al. (2010), but our study (Donskoi et al., 2010b) shows that the ore composition is very important from the point of view of ultrasonic application. For example, our current research shows that the effect of ultrasound on magnetite ores with quartz is insignificant (Donskoi et al., 2010b). The other critical issues would seem to be the interdependence between product grade and iron recovery, the dependence of ultrasonic effects on the experimental setup, and the relationship between ore size distribution and iron grade. These aspects were not studied by Pandey et al. (2010).

In the present study, further test work has been conducted on a set of iron ore fine samples derived from Australian hematitic/goethitic ores. During the experiments, ultrasonic treatment was applied to the samples with the aim of investigating the effect of various experimental parameters on iron, alumina and silica product recovery and grade for different iron ores. In particular, different pulp density, ultrasonic duration, power, and contact method were considered. Size assay analysis of feed samples and products of ultrasound treatments was undertaken to see whether significant improvements in iron grade were possible after sonication and calculated classification (de-sliming), and to determine the interdependences between the recoveries and grades of iron, alumina and silica for the various ultrasonic treatments.

2. Experimental

Sonication experiments were performed on four different hematitic/goethitic iron ores using three different ultrasonic setups and applying ultrasonic treatments for different durations. Products from the experiments were sized, and the size fractions assayed, to compare the size and elemental distributions before and after the ultrasonic treatments. The data were analysed to calculate the iron grades and recoveries after modelled perfect cut de-sliming.

2.1. Head samples

Four different iron ore fine samples (Ores 1, 2, 3 and 4) were examined. All were derived from Australian hematitic/goethitic ores. The ore fine samples described in this article as Ore 1 and Ore 2 were fractions from two different ores with size below 300 μm. Size distributions for these samples are given later in the text. The ore fine samples described as Ore 3 and Ore 4 were derived from the same ore. Ore 3 was the −250 μm size fraction of the original sample and Ore 4 was the −2000 + 1000 μm size fraction of the same sample. Quantitative X-ray diffraction analysis (XRD) was conducted on selected ores and size fractions from some experimental products to determine the phases present. The XRD results for Ore 1 and Ore 3 are given in Table 1. The data show that the major minerals in these ores were hematite and goethite with some presence of kaolinite, gibbsite and quartz.

The majority of the results reported here relate to tests conducted on Ore 1. Results from tests on the other ores are given if they were principally different from the results for Ore 1, or where demonstration of repeatability for different ore types was required.

2.2. Setup 1 — circulating pulp

The first experimental setup (Setup 1) is shown in Fig. 1. An ultrasonic probe was introduced into a vertical glass retort partially filled with the iron ore pulp. The power yielded by the ultrasonic probe was ~150 W. A small pump provided recirculation of the pulp through the system at a rate of 2 l/min. The pulp flow was almost laminar, but strong enough to avoid particle settling.

The total volume of pulp was 120 ml, while the active volume, i.e. the volume of the retort where the iron ore slurry was exposed to ultrasound, was approximately 20 ml. As the iron ore fines were only exposed to ultrasound while in the retort, the actual time of ultrasonic treatment was approximately 6 times less than the total time of the experiment (i.e. for a 2 min experiment, the actual time of ultrasonic exposure was 20 s). For the majority of the experiments, the amount of ore used was 24 g and the volume of water was 114 ml giving a pulp density of ~17% solids. In one test (Exp 4), the pulp density was increased to 41% solids. Sonication times varied from 2 to 18 min. Details of the experimental conditions for the tests are given in Table 2.

During all experiments using this setup, significant heating of the pulp was observed. For example, at the end of Exp 1 (2 min sonication), the pulp temperature had risen from 24 °C to 39 °C, while at the end of Exp 3 (18 min sonication), the pulp temperature had reached 80 °C.

Experiments with ores with larger particle size (>500 μm) were not successful with this experimental setup — the large particles became stuck between the ultrasonic horn and the experimental retort preventing the pulp from circulating properly.

2.3. Setup 2 — tank setup

The second experimental setup (Setup 2) is shown in Fig. 2. Pulp was placed in the experimental vessel together with an impeller (for stirring) and an ultrasonic probe. Power delivered via the ultrasonic probe was reduced relative to Setup 1 (~110 W compared with ~150 W). The main reason for decreasing the power was the interference caused by the rotation of the impeller — coverage of the probe was not stable, and the energy transfer from the probe to the

Table 1
Quantitative XRD results (wt.%) for selected size fractions of ores and experimental products.

Mineral	Ore or experimental product				
Ore	Ore 1	Ore 1	Ore 1	Ore 3	Ore 3
Product ID[a]		Exp 3, Setup 1, 18 min	Exp 3, Setup 1, 18 min		Exp 9, Setup 1, 6 min
Size range	−150 + 75 μm	−150 + 75 μm	CS6	−150 + 75 μm	CS6
Hematite	62	75	48	63	39
Goethite	31	24	47	30	48
Kaolinite	3	–	4	4	10
Gibbsite	–	–	<1	2	2
Quartz	4	<1	<1	<1	<1
Halite	–	–	<1	–	–

[a] The product ID consists (in sequence) of the experiment number, the setup number and the duration of sonication.