Separation Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713708471

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To cite this Article Celik, M. S.(1989) 'Effect of Ultrasonic Treatment on the Floatability of Coal and Galena', Separation Science and Technology, 24: 14, 1159 — 1166
To link to this Article: DOI: 10.1080/01496398908049894
URL: http://dx.doi.org/10.1080/01496398908049894

SEPARATION SCIENCE AND TECHNOLOGY, 24(14), pp. 1159-1166, 1989

Effect of Ultrasonic Treatment on the Floatability of Coal and Galena

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Abstract

The effect of ultrasonic pretreatment on the floatability of coal and galena is examined. Sonication of coal treated with oxidizing and reducing agents prior to flotation is found to completely restore its hydrophobicity. Flotation of galena by xanthate under incipient collector conditions is improved by using different treatment modes. Sonication in the absence of collector followed by slime removal and conditioning with collector resulted in recoveries several times higher than those in the absence of sonication. A mechanism involving the formation of clean surfaces followed by the occurrence of microbubbles on the hydrophobic solid and the resultant enhancement in bubble-particle attachment is proposed to be responsible for improved recoveries. The results further demonstrate that ultrasonic treatment under appropriate conditions can achieve at least a 50% reduction in collector consumption in the galena/xanthate system.

INTRODUCTION

Reviews on applications of ultrasonics in metallic ore processing show that acoustic fields can produce conducive effects which are important in processes such as flotation (*1*). Most studies have examined the effect of ultrasound before flotation, e.g., removal of adsorbed layer of reagents from minerals (*2*, *3*), emulsification of flotation reagents (*4*), while other recent studies have revealed the effect of ultrasonic treatment during and post flotation processes (*5*, *6*). Generally, the effect of ultrasonic vibration depends upon the nature of the mineral and also the way ultrasound is applied.

Various investigators have shown that intensive acoustic fields can modify the state of a material, leading to chemical or dispersive effects (*1*). Chemical effects are characterized by cavitation and are accompanied by a local increase in pressure and temperature. As solid/liquid interactions are weaker than liquid cohesion forces, solid/liquid interfaces are more amenable to the formation of cavitation. Hydrophobic particles in water, in particular, experience even weaker solid/liquid interactions because cavitation occurs much more readily at such interfaces (*6*). The disruptions caused at a solid/liquid interface can modify the surface properties of minerals, leading to changes in the adsorption of collectors on minerals and, in turn, in their flotation recoveries.

On the other hand, dispersive effects are realized when ultrasound is applied to a pulp containing stabilizer such as surfactant; this results in the formation of an emulsion. Ultrasonication in this way improves the effectiveness of the reagent due to its more uniform distribution in the suspension and also in enhancement of the activity of the chemicals used.

In this study the effect of pretreatment by ultrasonication on the floatability of oxidized coal and galena is examined. The influence of such parameters as collector concentration, slime removal, and the duration of sonication on flotation response is elucidated.

EXPERIMENTAL

A bituminous A-type coal with 2.2% ash content was prepared by crushing, grinding, and sieving to obtain 50×100 mesh size fractions. The material was then passed through a dry magnetic separator to remove iron contamination. The floatability of this sample was determined using a column cell (65×110 mm) with a fritted glass disk for passage of gas and a glass propeller for agitation at 125 rpm.

Three grams of vacuum dessicated coal was conditioned in a 100 mL solution containing either oxidizing (100 mg/L $KMnO_4$) or reducing (10 g/L $SnCl_2$) agent for 3 min. The treated coal was then rinsed off several times with distilled water and then filtered. The treated coal sample was floated with methylisobutylcarbinol (MIBC) till completion using nitrogen at a flow rate of 20 mL/min. The samples floated in this manner exhibited practically no flotation. The unfloated coal sample was again washed and filtered and transferred into a 100-mL distilled water-containing graduated cylinder. This sample was subsequently placed at a fixed position in a Bransonic model ultrasonic cleaner for varying sonication periods. The treated samples without desliming were next floated with MIBC as discussed before.

High purity galena sample in the form of big lumps was crushed and ground in a dry state to obtain a 65×100 mesh size fraction which was kept in plastic zipper bags for subsequent usages. The potassium ethyl xanthate used as a collector was purified in the usual manner (*7*, *8*). Flotation of galena was performed in a modified Hallimond tube set-up (*9*). The lower part of the apparatus consists of a glass well with a fritted glass disk which is connected to a flowmeter and then to a nitrogen gas supply. A magnetic spin bar placed on the fritted glass disk together with a magnetic stirrer beneath it provides controlled stirring of the mineral in the solution. The nitrogen flow rate was maintained at 20 mL/min for 1 min. The natural pH of the solution under different conditions was found to be relatively constant (6 ± 0.1). The fraction of the mineral levitated during the test is calculated from the dry weights of the floated and unfloated materials.

RESULTS AND DISCUSSION

Effect of Ultrasonic Treatment on Coal Flotation

Bituminuous and lower rank coals undergo atmospheric oxidation upon prolonged exposure at ordinary conditions. Oxidation increases with time and temperature. The effect of oxidation on the flotation properties of coal has been studied by several investigators (*10–13*). Removal of the oxidized surface layer can provide means to study both the actual clean surface and the oxidation products. Various pretreatments have been proposed to clean the surface of coal and thus achieve flotation of oxidized coal. These are: use of NaOH, reduction by hot benzyl alcohol (*14*), scrubbing or mild grinding and use of amines (*11*). Ultrasonic treatment has been shown to improve flotation of coal due to better dispersion of the flotation pulp (*15*). In this study, ultrasonic treatment through removal of the treated surface layer has been carried out to ascertain the effect of ultrasonic cleaning on the floatability of treated coal.

The effect of ultrasonic treatment on the floatability of coal treated with oxidizing ($KMnO_4$) and reducing ($SnCl_2$) agents is illustrated in Fig. 1. In

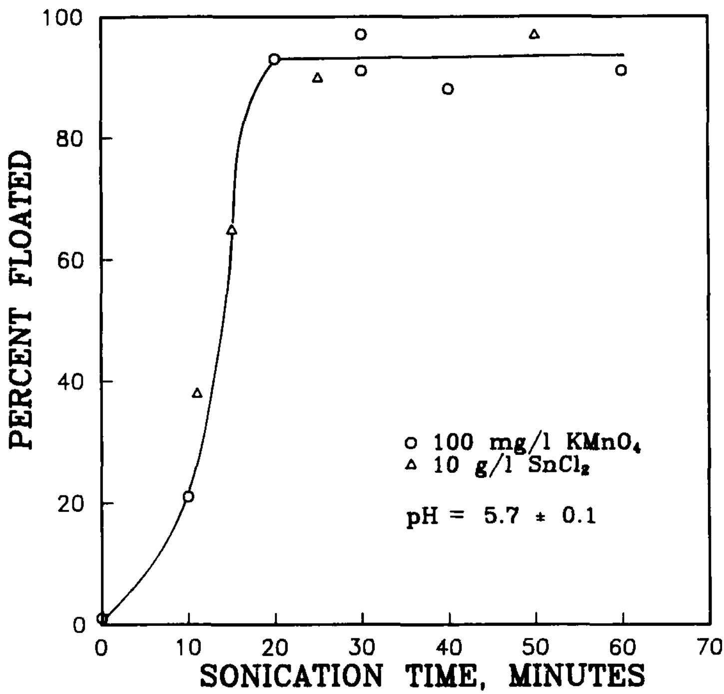

FIG. 1. Effect of ultrasonic treatment on the floatability of coal treated with oxidizing and reducing agents.

the absence of ultrasonic treatment, the flotation is nil. Ultrasonication evidently completely restores the floatability of coal above about 20 min of treatment time. It is noteworthy that cleaning of both $KMnO_4$ treated and untreated coal matrix by ultrasonication raised the isoelectric point of the coal (*2*). Also, electrokinetic behavior of the slimes obtained by ultrasonication of $KMnO_4$-treated coal was found to be similar to that of $KMnO_4$-treated coal itself (*2*).

Surface cleaning technique using ultrasonication can also enhance selectivity of oxidized coal flotation through exposure of clean surfaces which can be modified by subsequent chemical treatments. Problems in pyrite separation, for example, are partly due to the similar surface properties of fresh coal and unoxidized pyrite (*16*). Thus ultrasonic cleaning combined with a subsequent chemical treatment can succeed in pyrite separation. Ultrasonic cleaning can also remove adsorbed or precipitated hydroxy complexes of multivalent ions which can render the surface of coal hydrophilic and consequently depress its flotation (*17*).

Effect of Ultrasonic Treatment on Galena Flotation

Results obtained for the effect of ultrasonic treatment on the floatability of galena is illustrated in Fig. 2 under various conditions. Each number in the legend corresponds to a particular treatment mode, as discussed below.

(1) Conditioning time in the *x*-axis represents any conditioning in the form of either tumbling in a rotating mixer or sonication in an ultrasonic bath. Curve 1 in Fig. 2 was obtained by conditioning galena in xanthate without sonication. The floatability of galena increases marginally with

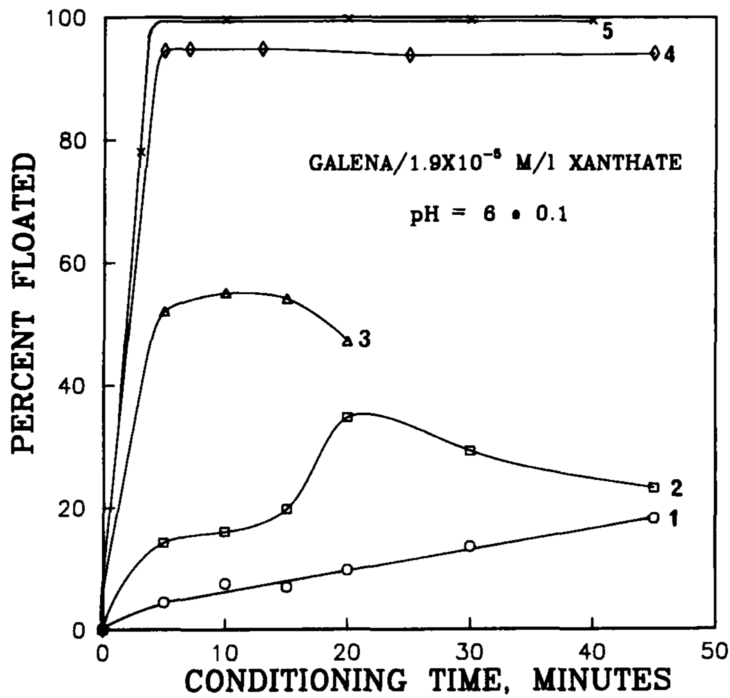

FIG. 2. Effect of various treatment modes on the floatability of galena (X = xanthate). 1: Tumbling with X, no sonication; no slime removal. 2: Sonication with X; no slime removal. 3: Sonication + stirring with X; no slime removal. 4: Sonication + stirring in distilled water + 10 min tumbling with X; no slime removal. 5: Sonication + stirring in distilled water + 10 min tumbling with X; deslimed.

increasing tumbling time. The flotation recovery is, however, rather low at this collector concentration; it was found that only by doubling the collector concentration could complete recovery be achieved. This incipient collector concentration was purposely chosen in order to see the effect of sonication on flotation recovery.

(2) In this step a graduated cylinder which contains galena and xanthate is placed at a fixed position in the ultrasonic bath. As Curve 2 shows, sonication improves the flotation recovery up to 20 min, but recovery decreases beyond this due to formation of excessive amount of slimes which consume the available collector and in turn reduce the percent floated material. Ultrasonic pretreatment of the pulp activates the galena surface for xanthate adsorption.

(3) Curve 2 was obtained without stirring the solution in the cylinder, whereas Curve 3 was obtained with an impeller mixing the solution as sonication proceeded. Addition of the stirring mechanism has apparently improved the recoveries substantially, though a decrease in recovery beyond a certain time again persists.

(4) Introduction of stirring in distilled water (no collector) while sonication is in progress prevented adsorption of some collector by slimes. Subsequent addition of tumbling with xanthate for 10 min led to substantial improvement in recoveries. Exposure of the clean galena surfaces which are more conducive to xanthate uptake resulted in higher recoveries, despite the presence of notorious slimes. This can be attributed to the competition of xanthate between the clean galena surface and oxidized slimes of high surface area; the former seems to be more favorable in increasing the flotation recoveries from about 55% (Curve 3) to 90% (Curve 4).

(5) Curve 5 corresponds to the conditions of Curve 4 except for the desliming step prior to flotation. The flotation recovery achieved was so high that there were practically no particles left in the cell; this indicates that under these conditions even lower collector concentrations could achieve a similar recovery.

The data obtained above reveal that ultrasonic treatment in the galena-xanthate system acts in two major ways: (a) it facilitates collector adsorption by exposing clean surfaces and produces high energetic centers on the solid surface, (b) it enhances bubble-particle attachment. The observed bubble-particle attachment in Step 5 was intriguing in that several bubbles loaded with galena particles formed a few distinct clusters. An explanation of the observed bubble-particle contact can be afforded in the following manner. Ultrasonification is known to promote the precipitation of gas particles followed by the formation of bubble nuclei. The deposition of such stabilized microbubbles, particularly on hydrophobic particles, can improve bubble-particle collision efficiency. This explanation is in accord with the experimental observations made in this study.

Slaczka (*6*) found that ultrasonic treatment increased the adsorption of collector on barite while it decreased that on fluorite. But collector adsorption on quartz did not exhibit any change upon ultrasonication. This was attributed to the differences in hardness and brittleness of these minerals. Ultrasonic treatment of barite led to the formation of micropits whereas fluorite exhibited a polishing action. Quartz was not affected by sonication. It should be noted that the ultrasonic treatment applied by Slaczka is much more intensive than the treatment made in this study. Because both coal and galena are rather brittle materials, these material are expected to show only a polishing action under very gentle sonication conditions.

Galena (PbS) oxidizes very rapidly both in water and particularly in air. The question of inherent floatability of galena is a subject of controversy in the flotation literature (*18*). Gutierrez (*19*) maintains the idea that even freshly crushed natural crushed galena has a partially oxidized surface due to its porosity unless oxidation products are washed off by suitable methods. In the present work the action of sonication seems to create a surface which is not only partially hydrophobic but also highly conducive to xanthate adsorption. Thus, even under incipient collector concentration, complete flotation recovery is achived.

However, the presence of slimes generally hinders bubble-particle attachment and leads to excessive collector consumption. This is particularly evident in Curves 2 and 3 and emphasizes the role of the desliming stage. The results presented above demonstrate that ultrasonic treatment under appropriate conditions can achieve at least a 50% reduction in collector consumption. The commercial application of an acoustic field in mineral processing primarily depends upon the efficiency and cost with which electrical energy can be converted to ultrasonic energy.

Acknowledgment

Suggestions made by Prof. C. C. Harris are gratefully acknowledged.

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Received by editor April 11, 1988