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Design of a flotation cell equipped with ultrasound transducers to enhance coal flotation

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Abstract

Ultrasonic treatment is widely used for surface cleaning during physical, chemical and physico-chemical processes in mineral processing. Several research papers and a few industrial applications about the subject suggest that the mechanism behind the positive effect of ultrasound for mineral processing and especially flotation is due to formation of cavitation by ultrasonic energy. Within this study, coal floatability is investigated by use of a specially designed flotation cell equipped with ultrasound transducers with different power, frequency and geometry. The results indicate that ultrasonic treatment during coal flotation positively affects the quality and quantity of the properties of floated coals while using of lesser amounts of reagent than a conventional flotation system.

Keywords: Mineral processing; Coal flotation; Ultrasound; Ultrasonics; Ultrasonic treatment

1. Introduction

Previous researchers who studied the separate phases of the flotation process postulated that it might be positively affected by mechanical vibrations, by the acoustic wave process or by a joint manifestation of these two physical phenomena. Some applications of ultrasonic treatment in mineral processing especially in flotation and extractive metallurgy, especially hydrometallurgy show that acoustic fields can produce significant positive impacts on recoveries of valuable products [1].

Most of the previous studies investigated the effects of ultrasonics before the flotation process takes place, e.g., removal of adsorbed layers of reagents from mineral surfaces, emulsification of the reagents. Recent studies about the subject concentrate on the effect of ultrasonic treatment during or after the flotation process. They state that the effectiveness of the ultrasound may be dependent upon the nature of the mineral's surfaces and also on the application method of ultrasound [2–5].

The introduction of ultrasonic energy into a flotation system could produce changes in the qualitative relationships in the system and cause a severe change of flotation rates. Some studies indicate that sound irradiation may change the pH values, surface tensions and oxidation–reduction potentials of flotation pulps. Previous researchers stated that application of ultrasound for flotation of various minerals, such as ilmenite, rutile and zircon even for a short period considerably increased their flotation response and gave significant changes in recovery and grade values. These improved values were believed to be due to the effective cleaning of particle surfaces from film coatings, namely slimes. The present author also studied the effects of ultrasonic treatment on flotation of colemanite–clays, magnesite–quartz and coal–ash [6–9].

The effects of ultrasonic treatment in a flotation system are generally characterised 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

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formation of cavitation. Hydrophobic particles are easily produced in a flotation pulp with the help of ultrasound with even weaker solid/liquid interactions, because cavitation occurs much more readily at such interfaces. The unsettled conditions caused at a solid–liquid interface can modify the surface properties of minerals, leading to changes in the adsorption of collectors on minerals and accordingly in their flotation responses. However, dispersive effects are realised when ultrasound is applied to a pulp containing a stabiliser such as a surfactant; this phenomenon concludes with the formation of an emulsion. Sonication can improve the effectiveness of a reagent due to more uniform distribution in the suspension and also in enhancement of the activity of the chemicals used [10–12].

Power ultrasound produces its effect via cavitation bubbles. When power ultrasound is applied to a liquid in sufficient intensity, the liquid is alternately subjected to compression and expansion forces giving rise to cavitation bubbles. When power ultrasound is applied to a mixture of particles and liquid and the bubbles collapse near a solid surface, a high-speed jet of liquid is driven into the particles and this jet can deposit enormous energy densities at the site of impact [13–16].

The interaction forces involved in physical adsorption of a reagent molecule are weaker than forces involved in chemical adsorption. The physical bond between reagent molecule and mineral surface can be easily broken by hydrodynamic turbulence created by ultrasound. In case of chemical adsorption, the interaction forces between reagent molecule and the mineral surface are stronger and can not be broken by the ultrasonification. Increased flotation recoveries in the presence of ultrasonic treatment could be explained by cleaning and formation of micropits on mineral surfaces with ultrasound [17].

Ultrasound facilitates reagent adsorption by exposing clean surfaces and produces high-energy centres on the mineral surface for the reagent molecule to adsorb, increasing flotation recoveries. Ultrasound is known to promote the precipitation of gas particles followed by the formation of bubble nuclei. The deposition of such stabilised microbubbles particularly on hydrophobic particles, can improve bubble–particle collision efficiency and therefore flotation recoveries are increased [18–21].

2. Materials and methods

Flotation tests were carried out on very finely sized hard coal slime samples supplied from the feed section of flotation section of the Prosper-Haniel Hardcoal Preparation Plant situated in Bottrop, Ruhr Region of Germany. Original particle size distribution, calorific value, ash and sulphur contents of the present coal slimes provided in pulp form from the plant are given in Table 1 in detail.

A Wemco type flotation machine with 1.25 L cell capacity and impeller speed of 1200 rpm was used during the current experiments. Ultrasonically assisted flotation tests were performed with newly designed and developed stainless steel flotation cells equipped with ultrasound transducers with different geometry, power and frequencies. Ultrasonic power generation was provided by a (2 × 300 W) generator with various power levels (at 10% intervals) and frequency modules (25 and 40 kHz).

Table 1
Original size distribution, calorific value, ash and sulphur contents of the sample (dry basis)

Particle size (mm)	Weight (%)	Ash (%)	Sulphur (%)	Calorific value (kJ/kg)
>0.500	3.20	2.12	0.84	34136
0.500–0.315	9.89	5.10	0.90	33286
0.315–0.250	5.94	13.41	0.86	30311
0.250–0.100	17.32	20.73	0.87	27259
0.100–0.050	9.82	29.21	0.93	23708
0.050–0.025	8.90	28.71	1.04	23666
<0.025	44.93	57.57	1.19	12721
Total (feed)	*100.00*	*36.25*	*1.04*	*21056*

The manufacturer of the ultrasonic equipment, Bandelin Electronic GmbH&Co. KG in Berlin built each transducer with 50 W power capacity and different dimensions according to different frequency requirements, i.e., 25, 40 and 25–40 kHz. The manufacturer reported that the overall energy loss might be approximately 10% and the electroacoustic overall efficiency per cell might be approximately 65%. The losses are independent of the frequency. During coal flotation experiments the ultrasonic power generator was run at up to 50% of its total output power during all stages of the process, i.e., conditioning and flotation.

Flotation operation parameters were chosen as 5 min of conditioning and 5 min of flotation time, variable amount Ekofol-440 reagent as coal flotation collector–frother combination. Bottrop mine site local water was used as the sample was in original pulp form with a rough solid ratio of 8–12%, ambient temperature, natural pH, electrical conductivity and oxidation–reduction potential of the slurry. Ekofol-440 is a trade name of the reagent with a basic combination of aliphatic alcohols in the C_6–C_{10} range free of phenols and phenol derivatives.

The schematic illustration of the new flotation system with all electrical connections and distributions is given in Fig. 1 in detail. Fig. 2 also shows the photo of the newly developed flotation system.

3. Experimental

Before the flotation experiments were carried out, effects of ultrasound on tap water, original coal–water slurry and reagent–coal–water were separately investigated against time intervals, ultrasonic frequency and power levels. For this reason, three-dimensional graphs were used and the results are given in Figs. 3–5 in detail.

The necessary variables were chosen as temperature, pH, conductivity and oxidation–reduction potential values against different ultrasonic power, frequency and time periods.