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Effect of microwave pre-treatment on the magnetic properties of iron ore and its implications on magnetic separation

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ABSTRACT

The use of microwave heating is a potential means of energy savings and is a more effective alternative to the conventional thermal processing of minerals. The effect of microwave treatment on Egyptian iron ore samples was investigated. Changing the microwave exposure time and power as well as their reflection on the magnetic properties of iron ore before and after microwave pretreatment was analyzed using different techniques. Microwave treatment was found to be more efficient at larger particle sizes and longer exposure times for a fixed value of the applied power intensity. Magnetic separation of microwave treated and untreated iron ore indicated that iron recovery increased from 39.54% in the untreated sample to 97.95% in the microwave-treated sample. The results indicated that microwave radiation has a significant effect on the magnetic properties of hematite through the formation of new and more magnetic phases that facilitate their separation from non-magnetic minerals, thereby obtaining high recovery, reaching ca. 98%.

1. Introduction

Microwave energy is a non-ionizing form of electromagnetic radiation with frequencies in the range of 300 MHz to 300 GHz. Microwave frequencies include three bands: ultra-high frequency (UHF: 300 MHz to 3 GHz), super-high frequency (SHF: 3 GHz to 30 GHz) and extremely high frequency (EHF: 30 GHz to 300 GHz) [1,2]. Microwave heating utilizes the ability of some materials to absorb electromagnetic energy in the microwave spectral range and transform it into heat [3]. Materials can be transparent to microwaves (such as silica), meaning that microwaves pass through the substance; reflective (e.g., metals); or absorb the microwaves (such as food) [2]. The heating of a material depends greatly on the ratio of the loss factor of the material to the dielectric constant. Materials with a high loss factor are easily heated by microwave energy [2,4]. Microwave heating is fundamentally different from conventional heating because microwaves can penetrate deep into the sample, which allows heating to be initiated volumetrically [5]. Conventional heating will heat the sample from the outside inward through standard heat transfer mechanisms, i.e., through convection, conduction, and radiation [5].

The magnetic properties of minerals can be improved by using microwave treatment [6]. The effect of microwave radiation on a number of minerals, e.g., chalcopyrite, hematite and wolframite, exhibited a considerable increase in magnetic susceptibility after being exposed to 650 W of microwave radiation [6]. Barani et al. [4] studied the effect of microwave radiation on the magnetic properties of iron ore. Their results indicated that microwave radiation has a significant effect upon the magnetic properties of iron ore. They found that the maximum attained temperature, magnetism saturation and remnant magnetization of iron ore samples increased with increasing exposure to microwaves [4]. The effect of microwave treatment on the magnetic processing of pyrite mineral was studied by Uslu et al. [7]. The results indicated that the magnetic susceptibility of pyrite could be increased by a considerable amount due to decomposition of pyrite to a strongly magnetic phase of pyrrhotite [7].

Waters et al. [8] found that when exposing pyrite to a microwave power of 1900 W for 120 s, the recovery of pyrite in the magnetic fraction after separation increased from 8% (wet) and 25% (dry) to greater than 80% for both process streams. The improvement in recovery was attributed to microwave radiation, which

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improves the magnetic properties of minerals [8]. Znamenackova et al. [3] found that the change of the magnetic susceptibility of siderite ore occurred after 10 min of microwave heating using a maximum power of 900 W. The values of magnetic susceptibility and the results of X-ray diffraction analysis confirmed the formation of new strongly magnetic phases [3]. Sahyoun et al. [9] investigated the influence of conventional heat treatment and microwave radiation on the magnetic properties of chalcopyrite [9]. Their results indicated a significant increase in the magnetic fraction recovery due to increased magnetic susceptibility after both conventional heating and microwave treatment. Guo Chen et al. [10,11] investigated the influence of microwave pre-treatment on the magnetic separation and surface characteristics of ilmenite ores. Chen et al. concluded that microwave treatment of ilmenite ore is a potential highly efficient technique for magnetic separation with low energy consumption. The influence of microwave irradiation on the grindability of gold ores was investigated [12]. It was concluded that microwave assisted grinding produced good results particularly for grinding characteristics.

The purpose of this investigation is to study the effect of microwave radiation on the magnetic properties of iron ore by using a vibrating sample magnetometer and its recovery using a wet high intensity magnetic separation technique.

2. Materials and experimental methods

2.1. Materials and sample preparation

The iron ore used in this study was collected from the Aswan region of Egypt. The eastern Aswan area represents the main occurrence of the Cretaceous ironstone bands of South Egypt, which are confined to clastic successions belonging to the "Nubian" sandstones or "Nubia facies" [13,14]. A representative sample was obtained from the Aswan region and was divided into representative batches of 100 grams each. Different size fractions of iron ore samples were prepared by crushing and sieving. These fractions are +8 mm, −8 + 4 mm, −4 + 2 mm, −2 + 1 mm, −1 + 0.5 mm, −0.5 + 0.25 mm, −0.25 + 0.125 mm, −0.125 + 0.0 65 mm, −0.065 + 0.032 mm and −0.032 mm. Fig. 1 and Table 1 present the XRD patterns and chemical analysis, respectively, of the iron ore sample. The following mineral phases were found: hematite, as a dominant component associated with quartz; chamosite' and fluoroapatite, as gangues. The chemical compositions of iron ore were as follows (%): ΣFe, 58.47; SiO_2, 7.48; MgO, 1.26; Al_2O_3, 4.47 (Table 1).

Table 1
Chemical composition of iron ore.

Oxides	Weight %
TFe	58.47
SiO_2	7.48
CaO	5.44
Al_2O_3	4.47
MnO	0.54
MgO	1.26

2.2. Thermogravimetry (TG–DSC) and mass spectrometry (MS)

The thermal behavior of iron ore was studied using thermogravimetry (TG–DSC) and mass spectrometry (MS), which was performed using a Netzsch STA409 PC Luxx under air atmosphere. Approximately 30.84 mg of sample was placed in a platinum crucible on a pan of the microbalance at a heating rate of 20 °C/min. The temperature range was 20–1250 °C.

2.3. Microwave treatment

Samples were treated using a 2.45 GHz microwave oven with a maximum output power of 900 W. Iron ore samples were treated in the oven for varying power levels and exposure times. One-hundred grams of the representative samples of different size fractions were used in each test. The samples were placed in the microwave oven in crucibles made of pure alumina. The temperature of the test sample was measured by quickly inserting the thermocouple into the sample after the power was turned off, and the temperature was monitored by a digital display temperature controller [15]. The measured temperatures are the bulk temperature of the samples. The samples were then allowed to cool in the microwave oven to room temperature.

2.4. The vibrating sample magnetometer (VSM)

The magnetic properties were measured at room temperature using a vibrating sample magnetometer VSM (7410 Lakeshore,

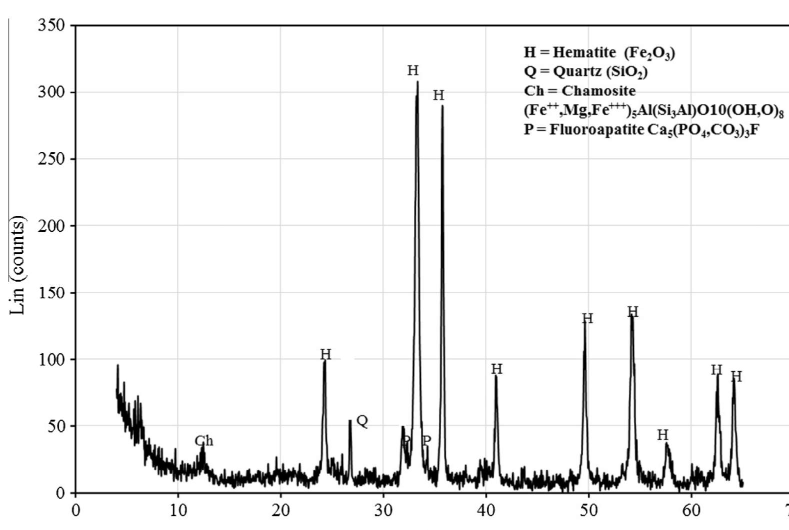

Fig. 1. X-ray diffraction pattern for iron ore.