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Dielectric properties and temperature increase characteristics of zinc oxide dust from fuming furnace

Li-bo ZHANG[1,2,3,4], Ai-yuan MA[1,2,3,4], Chen-hui LIU[1,2,3,4], Wen-wen QU[1,2,3,4],
Jin-hui PENG[1,2,3,4], Yong-guang LUO[1,2,3,4,5], Yong-gang ZUO[1,2,3,4]

1. Yunnan Provincial Key Laboratory of Intensification Metallurgy, Kunming 650093, China;
2. National Local Joint Laboratory of Engineering Application of Microwave Energy and Equipment Technology, Kunming 650093, China;
3. Key Laboratory of Unconventional Metallurgy of Ministry of Education, Kunming 650093, China;
4. Faculty of Metallurgical and Energy Engineering, Kunming University of Science and Technology, Kunming 650093, China;
5. Yunnan Chihong Zn & Ge Co. Ltd., Qujing 655011, China

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Abstract: Cavity perturbation method was used to determine the dielectric properties (ε', ε'', and tan δ) of zinc oxide dust in different apparent densities. The process was conducted to study the microwave-absorption properties of zinc oxide dust and the feasibility of microwave roasting zinc oxide dust to remove fluorine and chlorine. The dielectric constant, dielectric loss, and loss tangent were proportional to the apparent density of zinc oxide dust. The effects of sample mass and microwave power on the temperature increase characteristics under the microwave field were also studied. The results show that the apparent heating rate of the zinc oxide dust increases with the increase in microwave roasting power and decreases with the increase in the sample mass. The temperature of the samples reaches approximately 800 °C after microwave treatment for 8 min, which indicates that the zinc oxide dust has strong microwave-absorption ability.

Key words: zinc oxide dust; apparent density; dielectric properties; microwave heating; temperature increase characteristics

1 Introduction

Zinc is an important metal that is used in the metallurgical, chemical, and textile industries. It is extracted mainly from sulfide ore. A part of zinc is recycled from zinc-containing wastes such as zinc dust, zinc ash, and zinc dross. The zinc industry is developing rapidly but its operations are constrained by limited resources, energy shortages, and ecological and environmental problems [1−3]. A large amount of zinc oxide dusts are produced during the smelting of zinc, lead, and copper, as well as the scrap recycling process of galvanized steel. Zinc oxide dust has significant recovery and profit margin because of the high content of valuable Zn, Pb and In [4−6]. Zinc oxide dust obtained from a lead fuming furnace also contains a large number of fluorine and chlorine impurities during the zinc hydrometallurgy process; this condition results in equipment corrosion, high production costs, and low zinc recovery [7,8]. Thus, finding an effective method to solve these problems and reuse the secondary resource is necessary [9−11]. Currently, two main methods in fluorine and chlorine removal from zinc oxide dust are adopted: pretreatment removal and leach liquor removal [12,13]. However, both methods involve high energy consumption and management difficulties in the subsequent process. The microwave removal method is considered an environmentally friendly and energy-saving alternative.

As an efficient and clean form of energy, microwave heating has been widely used in mineral processing and metallurgy. Compared with conventional heating, microwave heating has the following advantages: fast

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Corresponding author: Jin-hui PENG; Tel: +86-871-5191046; Fax: +86-871-5138997; E-mail: jhpeng@kmust.edu.cn
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heating rate, volume heating, selective heating, easy automatic control, and the absence of environmental pollution. It can also reduce the reaction temperature, shorten the reaction time, and promote energy conservation [14−20]. With these advantages, microwave heating is introduced to remove fluorine and chlorine from zinc oxide dust. Microwave heating is employed in the microwave field dielectric loss of metallurgical material to ensure the overall heating of the material. The heating is determined by the material dielectric parameters (complex permittivity), which are key physical parameters to describe the interaction mechanism between microwave and dielectric materials. However, microwave heating is selective with regard to materials of different dielectric properties. Microwave selectively heats high-loss substances and low-loss substances that have no obvious absorption [21−24].

The dielectric properties (ε', ε'', and $\tan\delta$) of material are employed to describe the microwave absorption characteristics in the microwave heating process [25−28]. Dielectric properties can be defined in terms of relative permittivity (ε) composed of a real part (ε') and an imaginary part (ε''). The real part of the relative permittivity is known as dielectric constant and the imaginary part as loss factor. These properties can be expressed using the equation of $\varepsilon=\varepsilon'-j\varepsilon''$.

Loss tangent ($\tan\delta$) is a parameter employed to describe how well a material absorbs microwave energy. It represents the ratio of the dielectric loss factor to the dielectric constant ($\tan\delta=\varepsilon''/\varepsilon'$). The dielectric constant and loss tangent are functions of measurement frequency, material homogeneity and anisotropy, moisture, and material temperature.

The effects of various factors, such as microwave frequency, relative density and particle size of powder samples, on the permittivity and permeability were investigated. The ε' values of powders SiO_2 and Fe_3O_4 with the relative density below 1 are smaller than those estimated by the linear relation between ε' and the relative density, and larger than those estimated by the Lichtenecker's logarithm mixed law [29].

In this study, the cavity perturbation method was adopted to measure the dielectric properties of zinc oxide dust with different apparent densities. The zinc oxide dust temperature increase characteristics through microwave heating was also investigated to provide a theoretical basis for the removal of fluorine and chlorine from zinc oxide dust.

2 Experimental

2.1 Experimental materials

The zinc oxide dust used in this study was obtained from a lead and zinc smelting plant in Yunnan province, China. The main chemical composition of the zinc oxide dust sample is shown in Table 1, and its XRD pattern is presented in Fig. 1.

Table 1 Chemical composition of zinc oxide dust sample (mass fraction, %)

Zn	Pb	Ge	Cd	Fe	Sb
53.17	22.38	0.048	0.21	0.38	0.23
S	As	F	Cl	SiO_2	CaO
3.84	1.04	0.0874	0.0783	0.65	0.096

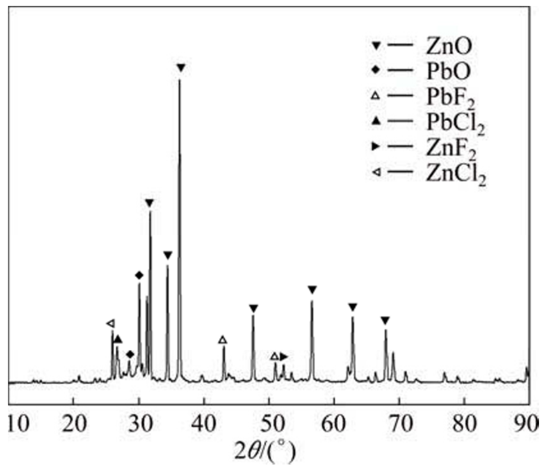

Fig. 1 XRD pattern of zinc oxide dust sample

As shown in Table 1 and Fig. 1, the zinc oxide dust sample contained a significant amount of lead and zinc, mainly in the form of lead and zinc oxides. Figure 2 shows three different morphologies of zinc oxide dust: cubic crystal structure, floc structure, and spherical structure. Zn mainly existed in the ZnO phase; Pb mainly existed in the PbO phases; while F and Cl mainly existed in zinc and lead halide. Certain amounts of fluorine and chlorine compounds were also found. The fluorine and chlorine compounds were dissolved in leaching solution during the leaching process. The excess content of fluorine and chlorine elements resulted in equipment corrosion, high production costs, and low zinc recovery in the subsequent zinc electrolysis process. Microwave was directly applied to roasting the zinc oxide fumes according to the different microwave absorbances among halides, lead, and zinc oxides in combination with the advantages of selective microwave heating, for the purpose of strengthening the separation of halides as volatile components.

2.2 Microwave heating system to measure temperature increase characteristics

The experiment equipment included a 3 kW box-type microwave metallurgical reactor developed by the Key Laboratory of Unconventional Metallurgy,