Physica C 471 (2011) 91–96

Contents lists available at ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc

Feasibility study of iron mineral separation from red mud by high gradient superconducting magnetic separation

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ARTICLE INFO

Article history:
Received 4 June 2010
Received in revised form 29 November 2010
Accepted 5 December 2010
Available online 13 December 2010

Keywords:
Red mud
Iron separation
High gradient
Superconducting magnet

ABSTRACT

The disposal of bayer red mud tailings now seriously threats the environment safety. Reduction and recycling of red mud is now an urgent work in aluminum industry. High gradient superconducting magnetic separation (HGSMS) system was applied to separate the extreme fine RM particles (<100 μm) into high iron content part and low iron content part. Two sorts of RM were fed in the HGSMS. The iron oxide contents in concentrates were about 65% and 45% when RM 1# and RM 2# were fed respectively. Meanwhile, the residues contained 52.0% or 14.1% iron oxide in residues after eight separation stages when RM 1# and RM 2# were fed respectively. The mass recovery of iron concentrates was about 10% after once separation process regardless of RM 1# or RM 2# was fed. Extreme fine particles (<10 μm) could be captured in the HGSMS. Intergrowth of Fe and other elements is disadvantages for iron mineral separation from RM by HGSMS. Some improvement should be studied to enhance the efficiency of iron separation. It is possible for HGSMS to separate RM into high iron content part and low iron content part, the former part could be used in iron-making furnace and the later part could be recycling to sintering process for alumina production or used as construction material.

1. Introduction

Red mud (RM) is a by-product after the caustic digestion of bauxite ores during the production of alumina. About 1–2 tons of RM residues (dry weight) are generated for a ton of alumina produced. At present, over 90 millions tons of caustic RM must be disposed of annually all around the world [1]. RM is a highly alkaline waste material with pH 10–12.5 and mainly composed of fine particles consist of aluminum, iron, silicon, calcium, titanium oxides and hydroxides. Such residue has accumulated over years and causes a serious environmental problem due to its high alkalinity and large amount. Currently, most RM generated from alumina plants is disposed in landfills or dumped at sea. The disposal and management of RM tailing residues constitute one of the most challenging problems facing the bauxite and alumina industry.

Up to now, in order to reduce the amount of RM, more and more researches had focused on the application of such residue tailings. RM has found limited applications in building materials [2], pigments and paints [3], metal recovery [4], catalysis, ceramic production [5], soil amendment [6], water or gas treatment [7], etc.

However, application of iron concentrated red mud with fine particles was limited. Take Shandong Branch, Aluminum Corporation of China for example, Fe_2O_3 consists from 30 to 60% in bayer red mud tailings with the particles size less than 100 μm. This sort of RM was disposed in landfills annually. Iron minerals separation from red mud with considered costs is significant for reducing red mud disposal [8]. High iron content RM could be used in iron-making furnace while the low iron content RM could be recycling in sintering process for aluminum production or used as building materials.

The main mineral phase of iron in bayer red mud tailings could be hematite, goethite or magnetite, etc. [8], which were magnetic or weak magnetic materials. Therefore, magnetic separation could be an attractive method to recover the iron minerals. Magnetic separation is a method for the separation of particles on the basis of their magnetic properties. Magnetic separation was found effective in recycling, purification [9] and other areas. The iron minerals can be efficiently separated by magnetic separation even if the precipitate is very fine. This is because the strong magnetic force (F_m) acts on magnetic particles when they move through a magnetic intensity (H) [10], the magnetic force (F_m) could be expressed as follows:

$$F_m = V \cdot M(H) \cdot dH/dx \tag{1}$$

where V is the volume of the magnetic particle, $M(H)$ is the magnetization of the magnetic particle in a magnetic intensity (H) and dH/dx is the magnetic gradients.

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doi:10.1016/j.physc.2010.12.003

When the magnetization of the particle gets saturated, F_m is shown in equation [11]:

$$F_m \cong \frac{4}{3}\pi b^3 M(H) dH/dx \quad (2)$$

where b is the radius of the dispersed particle. Consequently, magnetic particles are captured on a filter matrix by the magnetic tractive force (F_m) that overcomes other competing forces of gravitation, hydrodynamics and inertia, etc. The drag force (F_D) to the particle from the fluid is shown by:

$$F_D = 6\pi\mu b(v_f - v_p) \quad (3)$$

where μ, b, v_f and v_p are the fluid viscosity, radius of the spherical particle, fluid velocity and particle velocity, respectively.

Therefore, strong magnetic intensity (H) and high magnetic gradients (dH/dx) was needed for fine magnetic particles separation from the matrix. Traditional magnetic separation process was hard to separate the iron particles less than 100 μm [12]. Considering the extreme fine particles of RM, advanced magnetic separation method should be considered. In order to increase the magnetic properties of RM particles, Roasting methods followed by magnetic separation was studied by Liu et al. [8] for iron mineral separation from RM. However, roasting process was a high cost procedure which can hardly be used in industrial scale.

Superconducting magnets have a number of advantages over resistive electromagnets in fine magnetic materials recovery [13]. They can achieve an order of magnitude stronger field than ordinary ferromagnetic-core electromagnets, which can be more efficient in separating fine magnetic particles. Nowadays, the cost for superconducting magnets is considerable for industrial application because of the breakthrough of refrigeration system.

High gradient superconducting magnetic separation (HGSMS) process is now becoming a promising separation method for weakly magnetic minerals with fine particles. HGSMS had been used in kaolin refinement [14]. Radioactive water reducing and iron impurity removal from high-temperature boiler liquids in electrical power plants. However, the attempt of reducing RM tailings using HGSMS was never reported. Therefore, the main object of this work are (1) design a superconducting magnetic separation system, (2) attempt to separate iron minerals from RM and (3) discussing the improvement of using HGSMS in iron minerals recovery from RM.

2. Materials and methods

2.1. Red mud tailings

Iron content of RM has great discrepancy due to the bauxite used in bayer process. For example, there are two main types of RM (iron content about 30% or 60%) generated in Shandong Branch, Aluminum Corporation of China although the bauxites used in bayer process were both imported from Indonesia. These two types of RM tailings were both collected after the cyclone reactors. Meanwhile, the chemical compositions of the two types of RM tailings were shown in Table 1.

An X-ray diffractometer (ShimadzuXRD-6000) operated at 40 kV and 30 mA was used to identify the crystal structure and crystallinity with Cu Kα (l = 0.15418 nm) radiation over the range of 2 from 10° to 80°. The mineral phase of these two types RM shows little discrepancy, hematite, alumogoethite, anatase, quartz, sodium–silicon residue, $CaCO_3$, α-$Al(OH)_3$ were all detected. Meanwhile, the mineral phase of RM used in this work shows little discrepancy with other studies [15].

Table 1
Chemical composition of RM 1# and RM 2#.

%	SiO_2	Fe_2O_3	Al_2O_3	CaO	TiO_2	Na_2O	K_2O	Ignition loss
RM 1#	6.42	58.74	13.01	0.98	4.40	3.78	0.05	11.63
RM 2#	21.24	29.79	22.96	2.03	1.83	8.93	0.03	12.19

2.2. Superconducting magnetic separation systems

Magnetic separation process was carried out in a superconducting magnet (Institute of Electrical Engineering, Chinese Academy of Sciences, China). The HGSMS system was shown in Fig. 1 and a schematic diagram of this system is illustrated in Fig. 2. Approximate 1000 g carbon steel wool with a diameter of 50 μm was filled in a stainless steel column (100 cm height, 15 cm diameter).

2.3. Process of iron minerals recovery

Fig. 2 shows the continuous superconducting magnetic separation process that uses the concept of a reciprocating matrix. After a certain magnetic intensity was maintained, 1500 g RM (dry weight) were homogeneous dispersed in 25 L water which were pumped into the magnetic field (full with steal wool) by a submersible pump (2 T/h). The outflow from the steal wool matrix was recycled to the red mud tailing pool. After 5 min circulated-flow, the steal wool matrix was placed out of the magnetic field by a braking device. At the mean time, iron concentrated RM (concentrates) were washed out and collected by washing water using a water pump (12 T/h). The quality and iron content of concentrates, residues and steal wool retention RM were measured.

2.4. Methods of analysis

Iron content in red mud was measured by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES, Prodigy) after the solid phase was digested by microwave oven procedure (MARS, CEM). The digestion solution was Aqua regia (3 + 1 HCl–HNO_3). Size distributions were determined using a Malvern Mastersizer 2000 (Malvern Co., United Kingdom) with a ultrasonic deconcentrator, which ascertains size by analysis of forward scattered light. The micrograph and microanalysis of the samples were determined using a 30 kV HITACHI S-3000N scanning electron microscope (SEM).

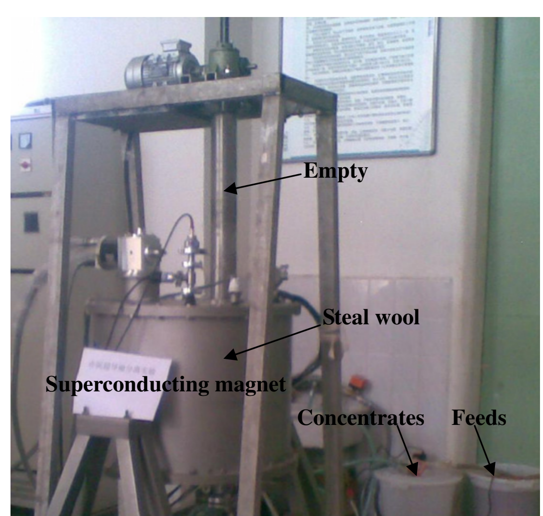

Fig. 1. Photograph of the high gradient superconducting magnetic separation system.