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Particulate matter filtration of the flue gas from iron-ore sintering operations using a magnetically stabilized fluidized bed

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ABSTRACT

This study proposes a novel process for the separation of particulate matter (PM) from the flue gas emitted from iron-ore sintering operations using a magnetically stabilized fluidized bed (MSFB) with sintered ore as a filter medium. The deactivated sintered ore can still be used as a raw material for subsequent sintering operations. Sintered ore and sintered ash samples were characterized by x-ray diffraction, x-ray fluorescence, and laser diffraction analyses. The effects of collector size (150–300, 300–450, and 450–600 μm), applied magnetic flux density (48–160 Gs), bed height (5, 7.5, and 10 cm), and gas velocity ratio (1.40, 1.51, and 1.62) on PM filtration are investigated. The experimental results indicate that PM filtration efficiency increases with increasing magnetic field strength and bed height. However, a high gas velocity ratio has negative effects on PM removal performance, while collector size has little influence. A comparative study of the MSFB for magnetic sintered ash and non-magnetic coal-fired ash filtration demonstrates that sintered ash is more effectively captured due to magnetic retention. This indicates that this technology has good prospects for the purification of flue gas from iron-ore sintering operations.

1. Introduction

Sintering is a thermal treatment applied to ferrous materials, fuel, and rhyolite for preparing suitable raw materials in the production of iron using a blast furnace [1]. The sintering process is the main source of pollutant emissions in iron and steel plants, and includes pollutants such as particulate matter (PM), SO_2, NO_x, Hg, polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) [2]; [3]; [4]; [5]; [6]. Increasingly stringent emission standards have progressively lowered the threshold limits of pollutant emissions worldwide. For example, China introduced the Emission Standard of Air Pollutants for Sintering Flue Gas (GB 28662–2012) in 2012, which required that PM concentrations of flue gas from sintering operations should be <50 mg/m^3 by 2015 [7]. This is a substantial challenge for some sintering plants.

Previous research [8]; [9]; [10]; [11]; [12]; [13]; [14]; [15]; [16] has investigated PM filtration from flue gas using fixed, fluidized or moving beds. Fixed-bed filtration generally exhibits high performance for small-diameter PM removal, and permits the passage of large gas flow [17]. However, the bed filter becomes gradually clogged with the collected PM, which progressively increases bed resistance. As a result, the filtration process must be halted while the bed is regenerated or replaced with fresh filter media. The inevitable downtime increases operational costs. One possible solution to this problem is to perform PM filtration using a fluidized bed or moving bed, which allows for the continual removal and introduction of the filter medium [18]. However, fluidized bed filtration suffers severely from the formation of gas bubbles that negatively affect the contact between PM and the filtration medium, resulting in relatively poor PM removal performance [19]; [20]; [21]; [22].

Based on above discussion, high-efficiency PM filtration can be obtained by restricting the formation of large gas bubbles in a fluidized-bed filter. In fact, gas bubbles can be eliminated entirely by maintaining the homogeneous gas fluidization of a fluidized bed of ferromagnetic particles via the application of an external magnetic field [23]; [24]. Such a system is denoted as a magnetically stabilized fluidized bed (MSFB). These systems offer the combined advantages of a conventional fixed bed (high filtration efficiency) and a fluidized bed (continuous operation). Studies have demonstrated the feasibility of MSFB systems for non-magnetic PM filtration (e.g., fly ash from coal-fired power plants and talc powder) [25]; [26]; [27]. The removal efficiency mainly depends on the effects of inertial impaction, interception, and Brownian diffusion [25]. However, few studies have focused on magnetic PM filtration using an MSFB, particularly for flue gas from iron-ore sintering processes, which is mainly composed of ferromagnetic iron oxide fly ash. In addition, MSFB systems have unique competitive advantages in comparison with conventional PM removal systems (i.e., electrostatic precipitators). For example, an MSFB system is suitable for high-temperature and high-pressure applications, and its PM removal

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efficiency is not influenced by dust resistivity. Therefore, exploring the application of MSFB systems to the filtration of sintered ash derived from iron-ore sintering operations is of great significance.

This work proposes a novel technology for the PM filtration of flue gas from iron-ore sintering operations using an MSFB in which sintered ore is adopted as the filter medium. A schematic illustrating the overall technological process proposed for the PM filtration of flue gas from sintering is given in Fig. 1. It is of interest that the filter medium was obtained from the sintering plant itself, and the deactivated sintered ore can still be employed as a raw material for subsequent sintering operations. The effects of various experimental variables, including collector size, applied magnetic field strength, bed height, and gas velocity ratio, on PM removal were investigated. Furthermore, a comparative study of the MSFB for magnetic sintered ash and non-magnetic coal-fired ash PM filtration is conducted to evaluate the role magnetic PM plays in the removal process.

2. Experimental

2.1. Sample preparation and characterization

The sintered ore and sintered ash employed in this study were obtained from a large-scale iron-ore sintering plant. The sintered ore employed as filter medium was first crushed and sieved to various particle sizes (150–300, 300–450, and 450–600 μm). Prior to use, the sintered ash was dried at 105 °C for 12 h to avoid agglomeration.

The crystal structures of the sintered ore were determined by x-ray diffraction (XRD; Empyrean, Poland), and their elemental compositions were measured by x-ray fluorescence (XRF; EDAX Inc., USA). The mean particle size and size distribution of sintered ash were measured by laser diffraction (LD; Mastersizer 2000, Malvern).

2.2. PM filtration experiments

A schematic of the PM filtration apparatus employed for testing is shown in Fig. 2. This apparatus was mainly composed of a gas supply system with a mass flow controller (MFC), a PM generator (PEF-90AL, Japan), a fluidized bed reactor, a magnetic field generator (HLY16–150, China), a differential pressure gauge (GM511, China), and a sampling system. The fluidized bed reactor was fabricated of methyl methacrylate with a height of 80 cm and an inner diameter of 2 cm. Stainless steel mesh (100-mesh) was adopted as the distributor of the MSFB reactor. A uniform axial magnetic field was generated by one-dimensional Helmholtz coils with a maximum current of 6 A. The coils were coaxial with the fluidized bed reactor, and the average coil diameter was 32 cm. The distributor was located at the same level as the center plane of the bottom coil. The differential pressure gauge measured the bed pressure drop before and after the filter medium in the range of 0–5 kPa.

The experimental steps are given as follows. Sintered ore was placed into the MSFB reactor to a desired bed height (L; 5, 7.5, and 10 cm). The magnetic field generator was adjusted to provide various magnetic flux density values (B; 48, 56, 64, 72, 80, 96, 128, and 160 Gs). Then, N_2 was fed into the PM generator to maintain a PM concentration of 5 g/m^3, which is in good agreement with the PM concentrations in actual flue gases derived from sintering operations. The PM-containing gas was subsequently input into the MSFB reactor. Each filtration experiment was conducted for 30 min. Finally, PM at the outlet of the MSFB reactor was accumulatively collected by commercially available glass fiber filters. The PM removal efficiency (η) was calculated by the following formula:

$$\eta = [(C_{\text{in}} — C_{\text{out}})/C_{\text{in}}] \times 100\% \quad (1)$$

Here, C_{in} and C_{out} denote the inlet and outlet PM concentrations (g/m^3), respectively. In addition, each experiment was repeated three times under equivalent conditions to ensure a maximum error within 5%.

3. Results and discussion

3.1. Sample characterization

Table 1 presents the particle size distribution of the sintered ash PM employed in the experiments. As shown in the table, particle sizes in the range 1–40 μm accounted for >62% of the sample, and the average particle size was calculated to be 38.38 μm. The elemental compositions of the sintered ore and sintered ash samples obtained by XRF are listed in Table 2. The sintered ash consisted of 40.08 wt% Fe, 23.89 wt% Cl, 16.19 wt% K, 9.57 wt% Ca, 7.15 wt% S, 2.02 wt% Si, and smaller amounts of Cu and Zn. However, the sintered ore consisted of 80.98 wt% Fe, 12.68 wt% Ca, 4.86 wt% Si, 1.18 wt% Cl, and smaller amounts of S, Cu, and Zn. The XRD analysis results shown in Fig. 3 indicate that the main phases found in sintered ore were hematite (Fe_2O_3) and magnetite (Fe_3O_4). The magnetic properties of the sintered ore and ash are

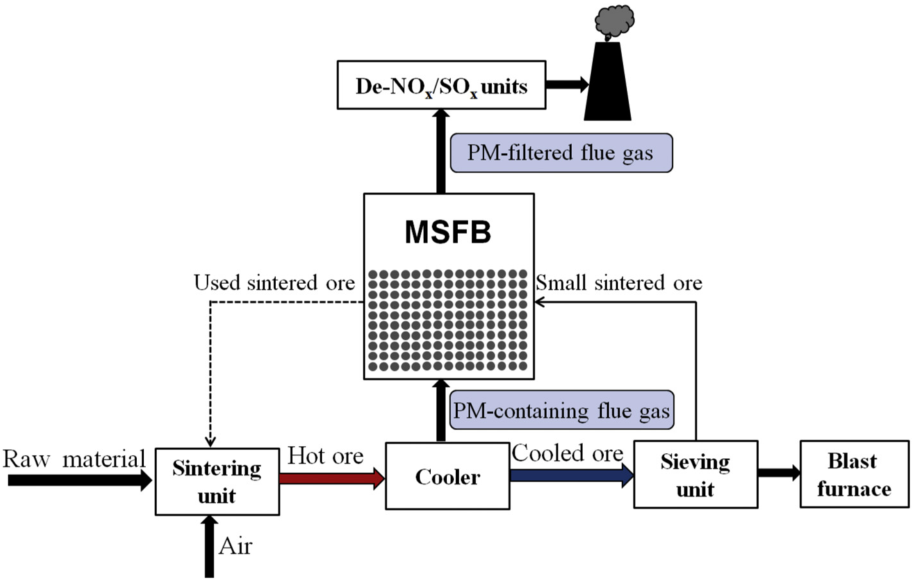

Fig. 1. Schematic illustrating the proposed technological process for PM removal using an MSFB.