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Characteristics of charcoal combustion and its effects on iron-ore sintering performance

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HIGHLIGHTS

- Detail thermal profiles and gas concentrations in sintering process were obtained.
- Equivalent fixed carbon replacement was proposed to ensure sufficient heat supply.
- Effects of charcoal size and distribution on combustion rate were presented.
- Sintering performance was improved with coarse and coated charcoal combustion.

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ABSTRACT

Using biomass for partial or complete replacement of coke breeze in iron ore sintering process is an attractive technique for reducing emissions of greenhouse gas and gaseous pollutants. But one drawback of this technique is that low or medium grade charcoal may lead to the failure in achieving proper sintering performance. In this paper, the behaviors of coke combustion versus charcoal combustion in sintering bed were compared. The results of thermal profile and exhaust gas composition indicated that the sinters quality was deteriorated at high charcoal proportion. Lacking heat release in melting zone and the excessively high combustion rate were the reasons to weak sinters. In order to ensure the sintering performance when using medium grade charcoal in sintering bed, the effects of three improving measures (proposing the equivalent fixed carbon substitution approach, increasing charcoal particle size and adopting coated charcoal combustion) were experimentally tested. The results showed that equivalent fixed carbon substitution approach was more effective to produce sufficient heat in melting zone at medium grade charcoal combustion. Additionally, it was also found that increasing charcoal particles size and applying coated charcoal combustion method could reduce combustion rate to achieve a proper matching condition between flame front speed and heat transfer front speed. Consequently, with the help of equivalent fixed carbon substitution approach, coarse charcoal and coated charcoal particles, the peak temperature, holding time above 1100 °C, melting quantity index and combustion efficiency were increased in the charcoal sintering process.

1. Introduction

Iron ore sintering is a pre-treatment technology to convert ore fines into porous and permeable sinters which are the most important burden materials for blast furnace. The main process is shown in Fig. 1 and described in [1]. There are many similar phenomena in industrial applications: oil shale (semi coke) combustion in fixed bed [2–4], Non-aqueous phase liquids (NAPLs) remediation [5,6] and combustion of municipal solid waste (MSW) or biomass particles [7–9] which are referred to as the reactive porous medium combustion in a fixed bed, also known as filtration combustion [10,11]. Generally, in the iron ore sintering process melting phase provides the coherency needed for high strength sinter. The amount of melt generated is highly dependent on the residence time at temperature of greater than 1100 °C. Other than residence time, the amount of melt formed will also depend on maximum temperature reached since this influences assimilation kinetics [12]. Machida [13] conducted a simple experiment to valid the relation between sintering strength and the residence time above melting temperature. Iwami [14] successfully developed gaseous injection technology to improve thermal conditions for higher sinter quality. Yasumoto [15] even fitted a correlation between shatter index (a kind of quality index) and thermal parameters

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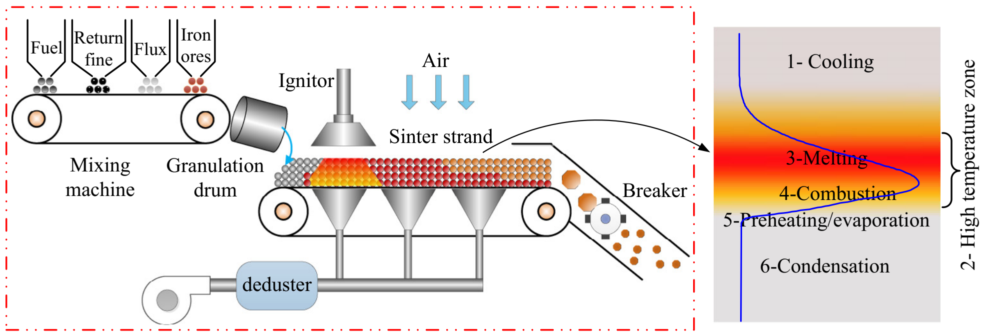

Fig. 1. Schematic diagram of iron ore sintering process.

on the basis of a series of experimental data. Several researchers used combustion and thermal characteristics to predict sinter quality when testing the alternative fuels or new sintering technology [16–19]. Therefore, sinter quality can be predicted by the thermal conditions provided by solid fuel combustion to some extent.

Conventionally, coke breeze is employed to provide heat needed for melting, which has been numerically and experimentally studied [16,20–25]. However, the increasing cost and environmental issue of coke breeze necessitate the efforts to seek for alternative fuels, such as anthracite, petroleum coke and biomass. The effect of less expensive anthracite coal on iron ore sintering was evaluated in [16]. From a longer-term view, fossil energy should be gradually replaced by renewable energy with low cost. Biomass is an environmental friendly source for industrial production due to its carbon neutral, lower NOx and SOx emissions. In the last decade, the co-firing of coke breeze and biomass in iron ore sintering has drawn extensive attention of researchers. Lovel et al. [26] performed small-scale sintering pot experiments using three different kinds of chars. The results suggested that there were no apparent technical barriers for utilizing high grade charcoal (94.3% fixed carbon content) in sinters production. But the supply shortage and high cost of high grade charcoal were the main problems for sinter plants. Ooi et al. [1,17] examined the combustion characteristics of sunflower seed husk and charcoal in sintering process. The organic pollution emissions in exhaust gas were also analyzed. It was found that, the proper substitution of coke breeze were 10% for sunflower seed husk, and 20% for charcoal, respectively. The authors claimed that low sintering performance at high biomass proportion was probably due to the low fixed carbon input. The effect of fuel reactivity on sintering speed, combustion efficiency and tumble index was also examined [27]. The results indicated fuels with high reactivity contributed to excessively high combustion rate, which resulted in low combustion efficiency. Zandi et al. [18] reported the emissions of NOx and SO_2 in biomass sintering process and measured the bed temperature at 25% biomass substitution. It was observed that, the peak temperature was lower than that of coke combustion. Lu et al. [28] explained the reasons for weak sinters at high biomass proportion. The emission mechanisms of CO, CO_2, SO_2, NOx and H_2O were carefully analyzed. Gan et al. [29,30] presented the flame acceleration mechanism in biomass iron ore sintering. Kawaguchi et al. [31] performed sintering experiments using raw biomass and carbonized char. Sintering yield and combustion efficiency were low when raw biomass was used directly. The authors claimed that it is necessary to control the operating parameters for high sinters quality, such as fuel particles size and biomass grade.

Biomass would bring great benefits for reducing the emissions of greenhouse and pollutant gases in sinter plants. However, the introduction of biomass, especially low and medium grade biomass, would result in weaker thermal conditions and sinters quality. Low fixed carbon input and excessively high combustion rate may be the primary causes.

- Low fixed carbon content

The volatiles in solid fuel thermally decompose at low temperature. They are partially oxidized in the downstream of combustion zone. Their low oxidization temperature is not sufficient for the iron ores melting [1,31]. In fact, sintering quality is highly dependent on the amount of melt phase which begins to form at a high temperature of 1100 °C [16,21]. Therefore, oxidation of volatiles is rarely helpful to the melting process. The high oxidation temperature of fixed carbon in solid fuel is crucial to sintering quality rather than the oxidation of volatiles. Moreover, lower oxidation rate of fixed carbon than that of gaseous oxidation is helpful to hold longer time for producing more melt phase.

- Excessively high combustion rate

Compared with coke breeze, complex internal pores in biomass result in higher specific surface area, which provides more opportunities for oxidizer reacting with carbon materials. Thus, high combustion rate in sintering bed accelerates the propagation speed of reaction front with the increase of biomass proportion [29–31]. According to the theory proposed in [10], it is helpful for energy accumulation in high temperature zone when the speeds of heat transfer front and flame front are close. As described in Appendix A, the heat transfer front speed can be estimated by:

$$\upsilon_{\mathrm{HTF}} = q_m c_g \Big/ \left[\varepsilon \rho_g c_g + (1-\varepsilon)\rho_s c_s\right] \qquad (1)$$

We can see that υ_{HTF} keeps more or less unchanged at the same operating parameters. Therefore, from the view of matching condition between flame front speed and heat transfer front speed, acceleration of flame front weakens the energy accumulation in sintering process.

Unfortunately, little work was reported on the influence of charcoal substitution approach on sintering performance. And few technical discussions were found on reducing biomass combustion rate for effective energy utilization, neither. It is meaningful to control combustion condition in sintering bed and avoid decline in sinters quality. Therefore, the objectives of our present work are to study the influences on biomass combustion performance in iron ore sintering process of three key parameters: the charcoal substitution approach, the charcoal particles size and the charcoal particles distribution in sintering bed. Meanwhile, some suggestions for improving charcoal combustion and energy utilization in sintering process are proposed.