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Can sodium sulfate be used as an additive for the reduction roasting of high-phosphorus oolitic hematite ore?

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ABSTRACT

A process of coal-based direct reduction roasting followed by magnetic separation was used to produce direct reduction iron (DRI) from high-phosphorus oolitic iron ore. The effect of sodium sulfate, which was used as an additive in the roasting process, was investigated. The addition of sodium sulfate increased the iron content and reduced the phosphorus content of DRI, but a sharp increase in the sulfur content of the DRI was observed. Although the S content of the DRI can be reduced to some extent by increasing roasting time as well as improving roasting temperature, its level is still too high for steelmaking. The results of scanning electron microscopy and energy-dispersive spectroscopy showed that when sodium sulfate was added, FeS was generated in the reduced briquette. FeS was intimately intermixed with metallic iron, which was difficult to remove. Therefore, sodium sulfate was not a suitable additive for the reduction of high-phosphorus oolitic hematite ore.

1. Introduction

Separation preconditioning involves the liberation of valuable minerals from the gangue minerals during mineral processing. However, many iron ores are so fine grained that grinding them to a sufficiently fine size to liberate the iron oxides from the gangues is impractical. Thus, these iron ores are currently not used (Srivastava and Kawatra, 2009). The fast depletion of easy-to-process iron ores and the exploitation of refractory iron ores are important global issues. Producing direct reduction iron (DRI) from difficult-to-process iron ores by coal-based direct reduction–magnetic separation has become a focus of research (Xu et al., 2012; Li et al., 2013, 2014; Jiang et al., 2010a,b; Yu et al., 2013). In this process, the iron oxides are reduced to metallic iron with grain growth and then were recovered by grinding and subsequent magnetic separation. The DRI product obtained by such process generally contains more than 90% Fe and was considered to be used as feed for steelmaking in an electric furnace. Sodium sulfate (Na_2SO_4) is typically used as an additive in the reduction process of refractory iron ores. Jiang et al. (2010a,b) reported that sodium sulfate addition increased the iron content of DRI and promoted dealumination for the reduction of a high-aluminum limonite ore. Xu et al. (2012) and Li et al. (2013) reported that sodium sulfate addition increased DRI iron content and promoted dephosphorization for the reduction of high-phosphorus oolitic hematite ores. However, information on the effects of sodium sulfate on the sulfur content of the DRI product is still lacking. Sulfur content of the feeds for steelmaking must be strictly controlled because too high concentration of sulfur will cause hot shortness of steel. If the addition of sodium sulfate resulted in a significant increase of sulfur content of the DRI, sodium sulfate will not be an appropriate additive.

In the present study, a high-phosphorus oolitic iron ore underwent the process of coal-based direct reduction followed by magnetic separation, and sodium sulfate was used as an additive in the roasting process. The effects of sodium sulfate dosage on the quality of DRI, especially on its sulfur content were studied. The phase transitions of sodium sulfate during the roasting and beneficiation processes were studied as well.

2. Experimental

2.1. Materials

A high phosphorus oolitic iron ore sample was obtained from Hubei province, China. It contained 43.58% Fe, 17.1% SiO_2, 9.28% Al_2O_3, 3.58% CaO, 0.83% P and 0.048% S. Iron mainly occurred in the form of hematite, and phosphorus occurred in the form of fluorapatite. This sample was exactly the same as that used by Xu et al. (2012), and similar to that employed by Li et al. (2013) except the latter has a higher Fe content and P content. The coal that was used as a reductant was obtained from Xinjiang province in China. Industrial analysis (air dry) showed that the coal had 6.55% moisture, 14.40% ash, 24.13% volatiles, 54.92% fixed carbon and 0.40% sulfur. The iron ore and coal used in the experiments were crushed to 100% passed 1 mm. The sodium sulfate used was of analytical reagent grade.

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2.2. Experimental procedure

The iron ore, coal, and sodium sulfate and an appropriate amount of water (8% to 12%) were fully mixed and pressed to briquettes in a steel die (30 mm in diameter) with a hydraulic press. One run used 20 g iron ore. Reduction roasting was performed in a muffle furnace after the briquettes were dried. The reduced briquettes were ground and separated in a magnetic tube. The methods of roasting, grinding and magnetic separation have been described previously (Yu et al., 2014). The evaluation indices for the test included iron, phosphorus and sulfur contents of the DRI and iron recovery.

2.3. Analysis and characterization

The chemical analyses of the DRI were conducted in the China University of Geosciences (Beijing) analysis laboratory. Scanning electron microscopy (SEM) with energy dispersive spectrum (EDS) (Carl Zeiss EVO18) analyses was performed on roasted briquettes mounted on epoxy resin and subsequently polished and carbon sprayed.

3. Results and discussion

3.1. Effect of sodium sulfate dosage on the roasting-magnetic separation

The effect of sodium sulfate dosage on the roasting-magnetic separation is shown in Fig. 1. The roasting temperature was fixed at 1050 °C and the roasting time was 60 min. The coal dosage used was 20%.

As the dosage of sodium sulfate increased from 0% to 10%, the iron content of the DRI increased from 83.97% to 93.58%, and the P content decreased from 0.27% to 0.057% (Fig. 1). These results agreed with those of previous studies (Li et al., 2013; Xu et al., 2012). However, the S content of the DRI also increased from 0.04% to 0.48% as the dosage of sodium sulfate increased from 0% to 10%. Moreover, the addition of sodium sulfate presented no significant effect on the recovery of iron. These results reveal that although the addition of sodium sulfate promotes dephosphorization, it introduces another harmful element of S into the DRI products.

3.2. Effect of roasting time on the roasting-magnetic separation with sodium sulfate addition

The effect of roasting time on the magnetic separation results was studied in the presence of 10% sodium sulfate, while the roasting temperature was fixed at 1050 °C and coal dosage at 20%. The results are shown in Fig. 2.

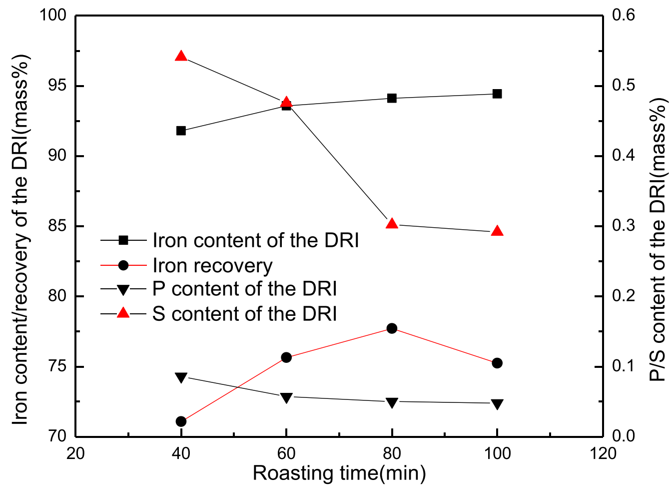

Fig. 2. Effect of roasting time on reduction–magnetic separation in the presence of 10% sodium sulfate.

It can be seen from Fig. 2 that, with an increase in the roasting time from 40 min to 80 min, the S content of the DRI decreased from 0.54% to 0.29%, while the iron content increased from 91.80% to 94.12%, P content decreased from 0.086 to 0.050% and the iron recovery increased from 71.08% to 77.71%. Further increasing the roasting time to 100 min gave no significant impact on the results of S content, P content and iron content of the DRI, while decreased the iron recovery to 75.24%. Therefore, the roasting time was fixed at 80 min in the subsequent experiment.

3.3. Effect of roasting temperature on the roasting-magnetic separation with sodium sulfate addition

Under the conditions that the dosage of sodium sulfate was 10%, the roasting time was 80 min and the coal dosage was 20%, the effect of roasting temperature on the magnetic separation results was studied. The results are shown in Fig. 3.

It can be observed that the S content of the DRI decreased from 0.40% to 0.24%, the iron content increased from 92.03% to 95.76%, and the iron recovery increased from 72.64% to 84.64% with increasing roasting temperature from 1000 °C to 1150 °C. However, the P content of the DRI increased significantly as the roasting temperature exceed

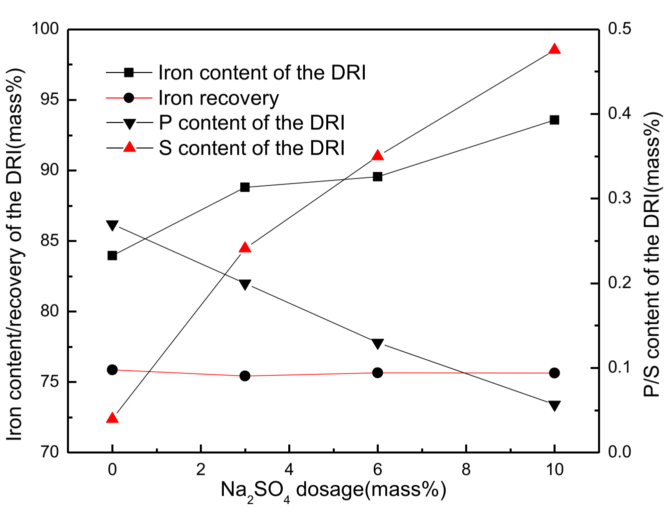

Fig. 1. Effect of sodium sulfate dosage on reduction–magnetic separation.

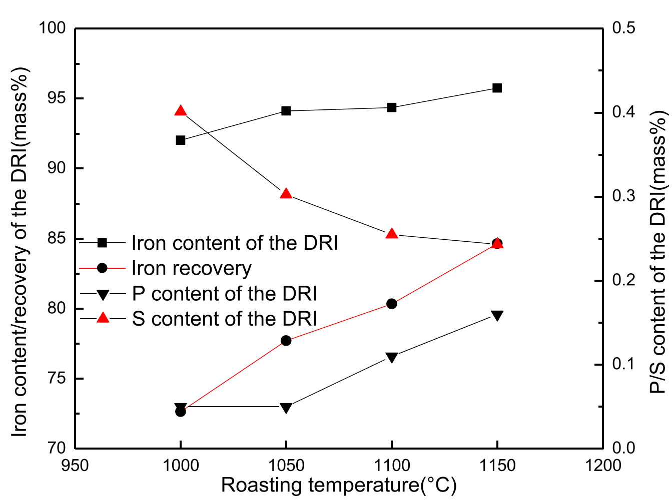

Fig. 3. Effect of roasting temperature on reduction–magnetic separation in the presence of 10% sodium sulfate.