



Effects of gas composition and temperature on the fluidization characteristics of carbon-coated iron ore



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ABSTRACT

To reduce the carbon content in the direct reduction iron (DRI) obtained via the two-step fluidized bed reduction process, we investigated the fluidization/defluidization behavior of the carbon-coated iron ore under different gas compositions and temperatures. It was found that the critical carbon content value ($C_{critical}$) needed to prevent defluidization increases obviously with increasing fluidization temperature, but is little affected by the gas composition, while the stability of the deposited carbon is highly dependent on the gas composition, i.e. when the H_2 mole fraction is greater than a certain critical value, the deposited carbon is unstable and will be constantly consumed during reduction, leading to the defluidization. Through the process optimization, the carbon content in DRI decreases to <5 wt.%, which is also much lower than those reported values of 16.5–22.3 wt.% in literature.

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1. Introduction

Fluidized beds are ideal reactors for non-blast furnace ironmaking due to their excellent heat and mass transfer efficiency, coke-free ironmaking and direct use of fine iron ore potential [1,2]. However, the serious defluidization problem during the reduction of fine iron ore, caused by the sticking of newly-formed metallic iron at elevated temperatures, always induces abrupt shut down of the equipment and hinders the stability of continuous operation in industry [3–5]. Among various defluidization prevention measures, carbon-coating is simple, effective, economical and draws more and more attention from recent researchers [6–10].

Generally for this method, a two-step reduction process is adopted, where pre-reduction process is conducted at relatively low temperatures for coating enough carbon on the surface of fine iron ore particles, to prevent the defluidization during the subsequent high temperature reduction process. One of the main problems lies in the fact that the direct reduction iron (DRI) obtained by such process contains a high carbon content (16.5–22.3 wt.%) as reported by previous studies [9,10], which is obviously too high to be used as the feedstock of following electric furnace steelmaking process. This can be attributed to two reasons: (1) the critical carbon content value ($C_{critical}$) needed to prevent the high temperature defluidization is too high, e.g., after pre-reduction process, the carbon content of a pre-reduced iron ore needs to exceed 13–

14 wt.% to totally avoid defluidization; (2) carbon accumulation during the subsequent high temperature reduction process, e.g., the carbon content of DRI further increased from 13.3 wt.% to 22.3 wt.% after reduction at 800 °C for 100 min as reported by D. Neuschütz [10].

To solve this problem, it is quite necessary to optimize the two-step direct reduction process. In our previous study [11], the $C_{critical}$ value was significantly decreased to 3.0–3.5 wt.% by the optimization of the pre-reduction process, based on the investigation of the fluidization/defluidization characteristics of carbon-coated iron ore under a fixed high temperature condition. This is the second paper focused on the optimization of the high temperature reduction process to further reduce the DRI carbon content. In the present study, we investigated the effects of gas composition and temperature on the fluidization/defluidization characteristics of carbon-coated iron ore, and further discussed the optimized reduction conditions

2. Experiment

2.1. Apparatus and raw materials

Fig. 1 shows the experimental apparatus, where the fluidized bed reactor is made of quartz, with an inner diameter of 16 mm and a height of 860 mm. The bed temperature is controlled by a PID controller and measured by an inserted k-type thermocouple with the accuracy of 1 °C. The flow rates of feeding gases are controlled by digital mass flow controllers, and the pressure drop of the bed is measured by a differential pressure sensor and recorded by a personal computer. The measuring range of the pressure sensor is 0–2 kPa and the accuracy is 0.5% of the full scale.

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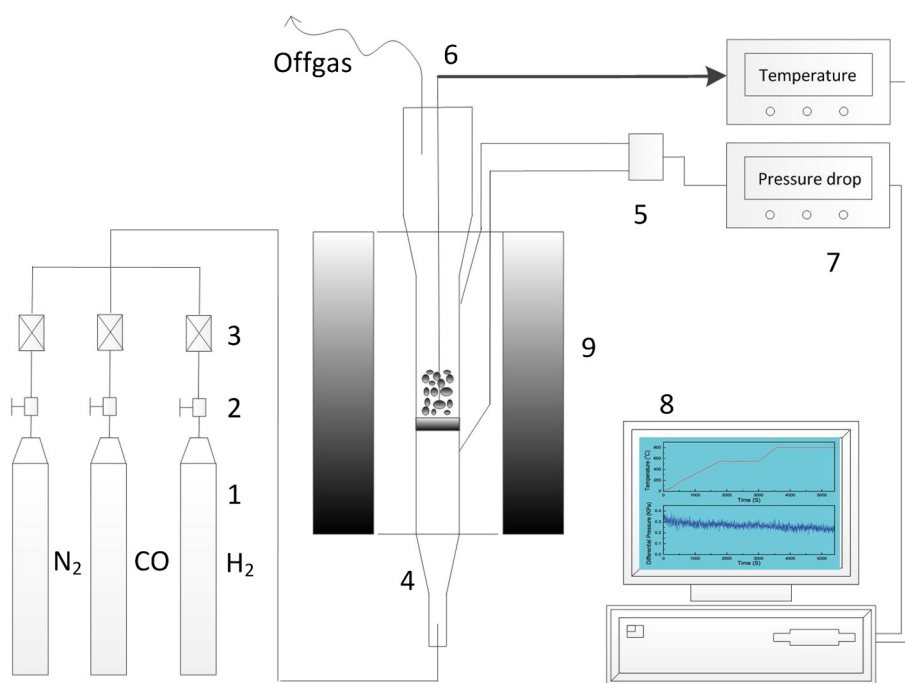


Fig. 1. Schematic diagram of the fluidized bed apparatus (1–Gas Cylinder; 2–Shutoff Valve; 3–Mass Flow Controller; 4–Fluidized Bed Reactor; 5–Differential Pressure Sensor; 6–Thermocouple; 7–Display Instrument; 8–Data Acquisition System; 9–Electric Resistance Furnace).

A Brazil iron ore with the particle diameter of 106–150 μm was used as the raw material in the present study. Its true density and bulk density are about 4939 kg/m^3 and 2209 kg/m^3 respectively, while its minimum fluidization gas velocity (u_{mf}) in N_2 at room temperature is about 3.2 cm/s . Table 1 shows its chemical composition. N_2 , H_2 and CO of 99.99% purity were used and supplied by Beijing Huayuan Gas Chemical Industry Co. Ltd., Beijing, China. All the carbon-coated iron ore samples were prepared by reducing the iron ore under the same pre-reduction condition, i.e., 1.5 L/min $\text{CO}-\text{H}_2$ mixture gas with H_2 mole fraction of 0.733 at 650 $^\circ\text{C}$. Fig. 2 shows the corresponding pre-reduction rate and carbon deposition rate. And the u_{mf} of such carbon-coated iron ore is in the range of 3.0–3.8 cm/s , depending on its composition.

2.2. Experimental procedure

The high temperature reduction process was conducted under atmospheric pressure. The fluidized bed reactor was pre-heated to 800 $^\circ\text{C}$ under N_2 atmosphere (1.0 L/min, about 29.6 cm/s), then 6.00 g carbon-coated iron ore were fed into the reactor (about 1.3 cm initial bed height) and N_2 was immediately altered to the desired reducing gas (1.5 L/min, about 44.4 cm/s). The used reducing gas was $\text{CO}-\text{H}_2$ mixture gas with a fixed CO/H_2 ratio, which was controlled by digital mass flow controllers. After the desired time or defluidization, the reducing gas was switched back to N_2 atmosphere (1.0 L/min, about 29.6 cm/s), and the reactor was removed from furnace and quenched directly by spraying water on its outer surface to the ambient temperature under N_2 atmosphere. Then the samples were transferred into zipper seal sample bag full of N_2 gas to prevent oxidation.

The carbon content of samples was measured by a carbon-sulfur analyzer (LECO CS-344, USA). The reduction degree of samples was measured by the titrimetric method according the national standard method of China (GB 223.7-2002). The off-gas composition was

analyzed by a gas chromatograph (INFICON 3000 Micro GC, USA). The fluidization behavior was characterized either by the pressure drop profile or by the direct vision. The defluidization time was determined from the fluidization pressure drop profiles.

3. Results and discussion

3.1. Effects of the initial carbon content

Fluidization/defluidization characteristics of carbon-coated iron ore with different initial carbon content (C_{initial}) were first investigated during the reduction at 800 $^\circ\text{C}$ in CO , to clarify the corresponding critical carbon content value (C_{critical}) needed for the defluidization prevention.

It was found that the fluidization quality increased with increasing the initial carbon content, e.g., when the C_{initial} is <1.2 wt.%, defluidization occurs due to the insufficient coating, as shown in Fig. 3(a). Defluidization can be prevented to a certain extent with the C_{initial} of 1.2–4.55 wt.%, where the pressure drop presents a ‘V’ type change with an initial decrease caused by partial defluidization at the beginning

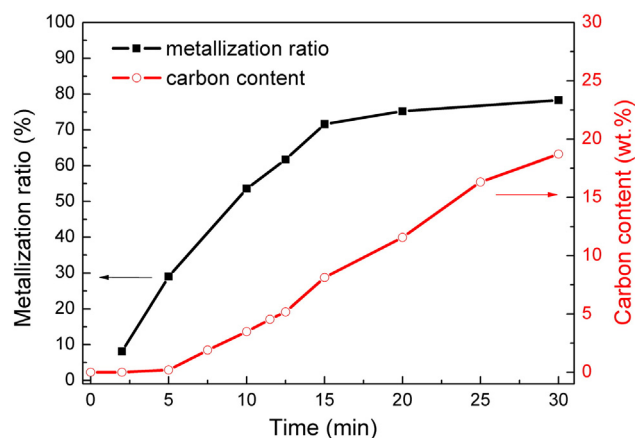


Fig. 2. Rates of reduction and carbon deposition during the pre-reduction process.

Table 1
Chemical composition of the Brazil iron ore.

Composition	TFe	Fe_2O_3	FeO	SiO_2	CaO	MgO	Al_2O_3
Weight (wt.%)	68.94	96.80	0.72	1.98	0.10	0.10	0.30

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