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# Effect of gas composition on reduction behavior in red mud and iron ore pellets

Yi Man [a,*], Junxiao Feng [b]

[a] School of Material and Metallurgy, University of Science and Technology Liaoning, Liaoning 114000, China
[b] School of Mechanical Engineering, University of Science and Technology Beijing, Beijing 100083, China

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ABSTRACT

In this study, mass loss and direct reduction characteristics of red mud and iron ore pellets in different atmosphere and temperature was investigated. The reaction kinetics parameters were estimated based on the experiments and different model equations. In addition, the phase transformation and microstructure of the reduction process were studied by X-ray diffraction technique (XRD) and Scanning electron microscope (SEM). The results show that the reduction process is three-dimensional phase-boundary controlled in $H_2$ and CO atmosphere. The rate of reduction in the presence of $H_2$ is significantly higher than in the CO atmosphere above 900 °C. 1100 °C and hydrogen atmosphere is optimum for the reduction of both iron ore concentrate and red mud pellets in the experimental conditions.



## 1. Introduction

The iron and steel industry is one of the largest energy consuming manufacturing industries in the world [1], accounting for 50%–70% of total production energy consumption of iron and steel industry in China. Iron ore and coke are the main raw material of iron and steel production. Due to the increased demand and the exploitation for many years, high quality iron ore and coke is dwindling. On the other hand, a large number of low grade ore and the metallurgical waste after production are seldom used. Traditional blast furnace iron demand high ore grade with long technological process and large investment scale. The energy consumption is high, and the pollution is serious, which is affecting the benign and sustainable development of iron and steel industry. In some countries, the traditional blast furnace has been partially replaced by direct reduced iron [2]. Over the past several decades, the reduction of iron ore has been widely investigated. Weiss [3] investigated the reduction kinetics of iron ore fines with hydrogen-rich gas mixtures in the temperature range from 400 to 700 °C. Halder [4–6] studied the shrinkage and reaction rates of Iron Oxide-Carbon Composites Pellets. The kinetics of isothermal reduction of the carbon bearing pellets was estimated applying thermogravimetry in the temperature range of 1000–1400 °C by Ding [7]. Piotrowski [8] applied thermogravimetry to estimate the reduction kinetics of $Fe_2O_3$ to FeO in the presence of syngas constituents. Iron ore reduction by the gaseous products of methane partial oxidation in a porous media was studied numerically and experimentally by Pablo [9]. Direct reduction of iron ore pellets with and without biomass was studied using hydrogen as the reducing agent by Guo [10]. However, the research on reduction behavior of metallurgical waste has been studied rarely. Red mud is the by-product in alumina manufacture which is primarily composed of iron [11–12]. Extracting metal iron from red mud and reusing the residue left as building material has both environmental and economic significance [13–16]. Li [17] investigated the recovery behavior of Fe-rich Bayer red mud through reduction sintering. Liu [18] applied magnetic separation to study the process to recycle Fe from red mud. Samouhos [19] investigated the recovery behavior of red mud with lignite through a microwave reductive roasting technique.

The objective of the present investigation is to study the effect of gas composition and temperature on reduction characteristics of iron ore and red mud pellets. For this purpose the thermogravimetry methods are applied to estimate the reduction kinetics in different atmosphere and the heated residues are identified by X-ray diffraction and scanning electron microscope.

## 2. Materials and experiments

### 2.1. Materials

The iron ore concentrate and red mud used in this work were obtained from Hebei and Shandong, respectively. The chemical composition is shown in Table 1.

The particle size of iron ore concentrate and red mud ranged from 74 μm to 147 μm. The crystalline phases were identified via X-ray

* Corresponding author.
*E-mail address:* 61796479@qq.com (Y. Man).

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**Table 1**
Chemical composition of the materials (mass/%).

| | Fe total | FeO | $SiO_2$ | CaO | $Al_2O_3$ | MgO | $Na_2O$ | $K_2O$ | $TiO_2$ | S | P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Iron ore concentrate | 66.8 | 26.1 | 4.39 | 0.17 | 0.62 | 0.51 | 0.011 | 0.012 | 0.062 | 0.053 | 0.039 |
| Red mud | 47.6 | 1.20 | 10.4 | 0.44 | 8.42 | 0.082 | 1.73 | 0.24 | 1.71 | 0.026 | 0.023 |

diffraction by applying Cu-Kα (λ = 0.15406 nm) radiation. The phases composition of both iron ore and red mud were shown in Figs. 1 and 2. The main mineral phases were hematite, limonite, diaspore, quartz in red mud and hematite, magnetite in iron ore concentrate. Pellets with the particle size of 15 mm were made of 1.5% bentonite binder in a disk pelletizer (diameter = 1000 mm, angle of inclination = 45°, and rotation frequency = 28 rpm). Then red mud pellets and iron ore pellets were dried in an oven for 2 h at 250 °C and 110 °C to wipe off the free moisture and crystal water. Experiments were carried out at temperatures between 700 and 1100 °C.

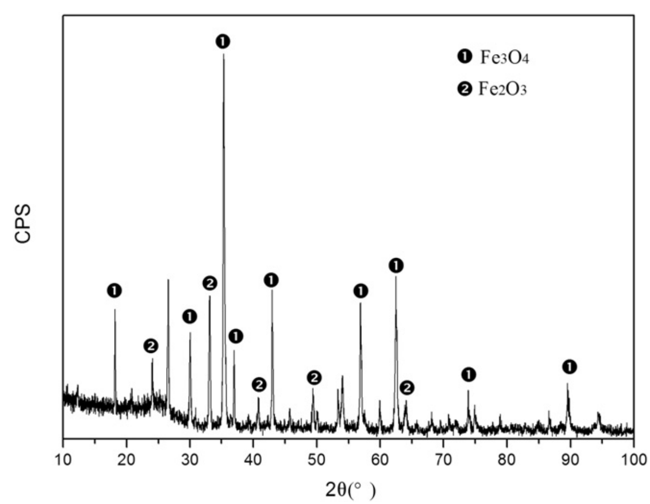


**Fig. 1.** XRD analysis of iron ore concentrate.

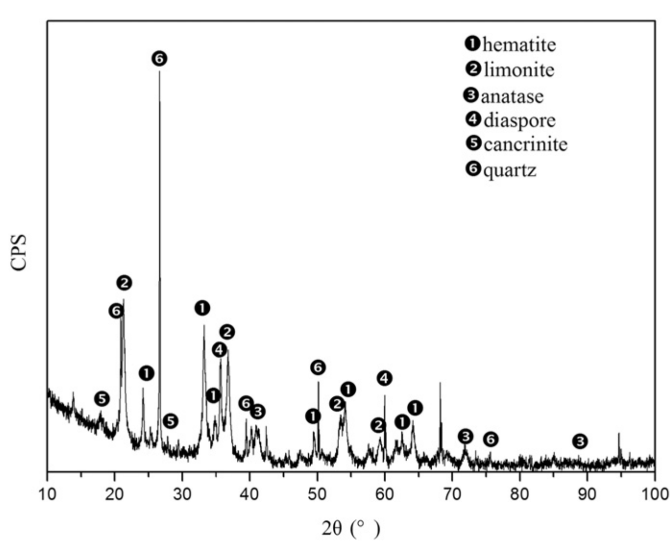


**Fig. 2.** XRD analysis of red mud.

## 2.2. Experimental

The experimental study described in this paper was carried out in a thermogravimetric analyzer apparatus. The thermogravimetric analyzer apparatus was made of an electric furnace, a quartz glass tube reactor and endowed with a gas distributor disk, an electronic balance and a temperature controller. Two group experiments (CO, $H_2$) were designed to investigate the effects of different gas composition on iron reduction from red mud and iron ore concentrate. In the experiments, nitrogen was used to eliminate the air, and then the thermogravimetric analyzer apparatus was maintained under experiment gas with a nitrogen flow of 2 L/min. The furnace was heated to the desired temperature. Then the samples were placed in heating zone. The mass of the samples were recorded by the electronic balance every 1 min. At the end of the experiment, the samples were removed from the furnace and cooled down under $N_2$ atmosphere to the ambient temperature.

The degree of conversion was defined as the following formula [20]:

$$\alpha(\mathrm{t}) = \frac{m_0 - m_t}{m_0 - m_{\mathrm{red}}} \tag{1}$$

Where $\alpha$ is the degree of conversion, $m_0$ is the initial mass of the sample after moisture removal, $m_t$ is the actual mass of sample, $m_{red}$ is the mass of the sample in the fully reduced form.

# 3. Results and discussion

## 3.1. Effect of gas composition on isothermal reduction

The effect of gas composition and temperature on reduction was investigated by monitoring mass changes in the reduction system. Figs. 3 and 4 were the curves of conversion degree of iron oxides and red mud with time under isothermal conditions (700 °C–1100 °C) in CO and $H_2$ atmospheres.

The investigation of the curves indicated that as the temperature increased from 700 to 1100 °C, the reduction degree of conversion increased for all samples. It is observed that the rate of reduction is

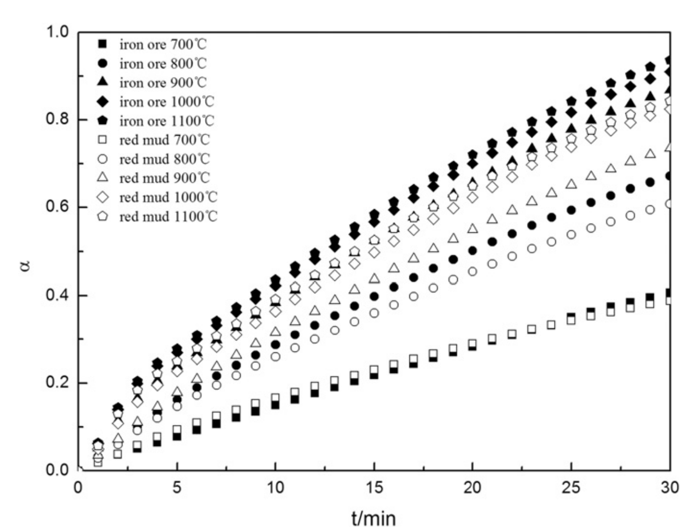


**Fig. 3.** Effect of CO atmosphere on reduction reaction.