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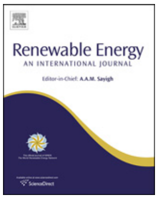

Direct reduction of mixed biomass-Fe_2O_3 briquettes using biomass-generated syngas

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ABSTRACT

This paper presents a novel ironmaking technology using biomass and iron oxide. The biomass instead of coke was mixed together with iron ore powder, water, limestone and bentonite for the production of Fe_2O_3 briquettes. The sintering process and direct reduction of briquettes were simultaneously conducted in the same reactor. Briquettes with different composition were isothermally reduced directly to metallic iron with H_2–CO mixtures at different temperatures (ranging from 900 to 1100 °C) and reaction time (30–60 min) to investigate the effects of briquettes composition, reduction temperature, reaction time and reducing gas composition on the quality of metallic iron. The results show that the increase of reduction temperature, reaction time and H_2 content of the reducing gas are favorable for the quality of pig iron, within the experimental conditions. At a reduction temperature of 1100 °C and reaction time of 60 min, the Fe content in product achieves the maximum 94.7%.

1. Introduction

Approximately 60% of the world's pig iron is manufactured using a blast furnace ironmaking technology. In China, the number amounts to 90%. There are several problems hindering the development of blast furnace ironmaking technology, especially the use of high quality coke in its production [1]. In a blast furnace, coke and ore are continuously supplied from the top of the furnace, and air is blown into the bottom of the chamber, so that the chemical reactions take place in the furnace as the materials move downwards.

In the blast furnace, incomplete combustion of coke provides the heat and reducing atmosphere for the iron ore reduction, which generates a large amount of low-calorific value blast furnace gas as a byproduct. In addition, the use of coke poses a serious problem: the exposure of hot metal to coke increases the percentage content of C in pig iron, generally around 4%. In the following steel making process, the hot metal is exposed to a pure oxygen atmosphere to eliminate the adverse effect of C (the aim is to improve the toughness of steel) arising from blast furnace ironmaking. The investment of coke production facilities is huge and even a modern production process results in a great deal of ecological and environmental pollution, which is difficult to overcome fundamentally. In addition, when the ash content of coke exceeds 20%, it will have adverse effects on the production efficiency as well as on the quality of pig iron. Moreover, higher ash content needs higher amounts of slagging elements for the generation of furnace slag.

In summary, the huge investment needed and increasing environmental protection requirements hamper the development of blast furnace ironmaking technology. The innovation of ironmaking technologies becomes urgent, especially in China.

At present, the development of non-blast furnace technology (direct reduction and melting reduction ironmaking) targets an independence of fossil fuel [2]. However, the new alternative fuels for metallurgical coke in the non-blast furnace technology are mainly coal and natural gas [3]. There are no fundamental improvements in environmental pollution control, especially concerning the carbon emissions. At the same time, higher energy consumption and poorer product quality limit the development of new technologies.

It is well known that biomass is a carbon-neutral and renewable source. Lower contents of harmful elements (S, P and others) and abundant raw material sources makes it feasible for the substitution of coke and coal in the manufacturing, since its use can reduce emissions of e.g. CO_2 and SO_2, reduce the energy consumption and reduce the content of harmful elements (S,P and others) in the product.

Few studies were carried out on ironmaking using biomass. Yuichi Hata [4] studied the possibility of using biomass for ironmaking by using dehydrated goethite ore and biomass. The

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Table 1
Samples composition used in the experiments.

Composition/g	Biomass	Coke	Iron oxide	Limestone	Bentonite
Sample 1		150	850	20	50
Sample 2		100	900	20	50
Sample 3		50	950	20	50
Sample 4	150		850	20	50
Sample 5	100		900	20	50
Sample 6	50		950	20	50
Sample 7			1000	20	50

reducing agent is char from the pyrolysis of biomass. Firstly iron ore was dehydrated at 450 °C to be porous (the dehydration is to create pores); subsequently, they were placed in the pyrolyzer of biomass, which was heated at 600 °C .The tar vapor generated was decomposed to deposit char within/on the porous ores. The ores containing char deposits were then heated up to 900 °C in a N_2 atmosphere for the reduction of iron oxide.

The production process is relatively complicated, and the Fe—C reduction intensity is weaker. Meanwhile the carbon deposited in the surface of iron ore prevents the reduction reaction among H_2, CO and iron oxide.

The production of syngas by catalytic steam gasification of biomass has been studied by numerous research groups [5–7]. Syngas is mainly composed of H_2 and CO can be used as reducing agent for the direct reduction of iron ore. In this paper, a novel direct reduction technology using biomass was presented. The biomass powder instead of coke was mixed together with iron ore powder, water, limestone and bentonite for the production of Fe_2O_3 briquettes. The sintering process and ironmaking process were simultaneously conducted in the same reactor, and the syngas (mainly composed of 50% H_2 and 20% CO) produced by biomass steam catalytic gasification [8] was selected as reducing gas.

During the reduction process, dehydration of combined water and pyrolysis of biomass make the briquette porous, increasing the contact area of iron oxide and reducing gas. At the same time, the limestone and bentonite act as catalysts to crack the tar into syngas and char during biomass pyrolysis, further improving the reduction degree of iron oxide.

The influences of reduction temperature, reaction time, and Fe_2O_3 briquette composition on metallic iron content in the product were studied to understand the reliability of the direct reduction technology using biomass.

Table 2
Ultimate analysis of iron ore powder.

Composition	TFe	SiO_2	Al_2O_3	CaO	MgO	S	P	Cu
Wt%	65.21	2.25	0.94	0.10	0.04	0.52	0.291	0.017

Table 3
Particle size distribution of iron ore powder.

Particle size/mm	>0.074	0.074 ~ 0.043	0.043 ~ 0.038	<0.038
Wt%	8.96	15.20	18.88	56.96

2. Experiment setup

2.1. Materials

Briquettes were made of iron oxide, biomass/coke, bentonite, limestone and water. The composition and appearance of Fe_2O_3 briquettes are shown in Table 1 and Fig. 1(a), respectively.

The addition of bentonite is to enhance the mechanical strength of the test samples. Bentonite, composed of $mAl_2O_3—nSiO_2—xH_2O$, has swelling, adhesion, adsorption and catalytic characteristics. Water acts as an adhesive. Fe_2O_3 briquettes were compacted in a cylindrical tube (8 mm in length and 10 mm in diameter) at 50 kg/cm^2.

Larger Fe_2O_3 briquettes particles counteract the diffusion of reducing gas and decrease the reaction rate, while too small particles will reduce the permeability of the packed bed of iron oxide, resulting in the uneven distribution of reducing gas.

The biomass, pine sawdust, was crushed in a lab-scaled crusher [9]. The particle size distribution by sieving was as follows: 61 wt% below 150 μm, 32 wt% 150–180 μm, 4 wt% 180–250 μm and 3 wt% above 250 μm.

The composition and particle size distribution of iron ore powder are shown in Tables 2 and 3, respectively.

2.2. Experimental facilities

The experimental apparatus was mainly composed of a cyclone furnace, screw feeder, corundum tubular reactor, centrifugal fan and temperature measurement system, as shown in Fig. 2.

The external heat source was provided by the combustion of biomass in the cyclone furnace [10]. The cyclone furnace was

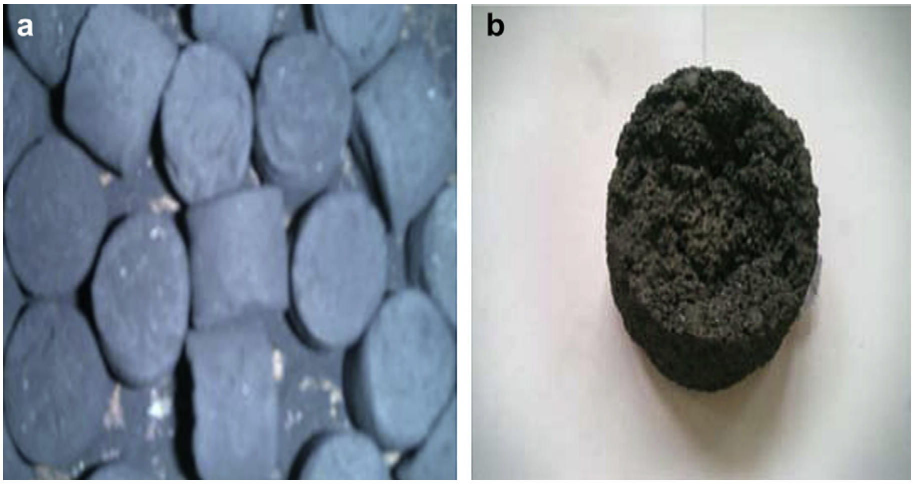

Fig. 1. Appearance of Fe_2O_3 briquette (a) and reduction product (b) made at 1000 °C, 60 min.