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Research article

Deposit formation mechanisms in a pulverized coal fired grate for hematite pellet production

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ABSTRACT

Pulverized coal combustion was adopted at the end of the grate to provide sufficiently high preheating temperature in the grate when hematite was roasted to produce hematite pellets. Unfortunately, serious deposit which stuck to the walls at the end of the grate was found after using pulverized coal combustion. In the present study, chemical analysis methods were used to detect the chemical compositions of the preheated pellet powder, deposit sample and coal ash. In addition, the major phases and microstructure of the deposit sample were determined using X-ray diffraction (XRD), scanning electron microscope (SEM) and energy dispersive spectrometer (EDS) analysis, respectively. Furthermore, a thermodynamic software (FactSage 7.0) was adopted to analyze the deposit formation process. The chemical and mineralogical analyses indicated that the deposits contained high amounts of iron, particularly of silicate, aluminum, calcium and magnesium and, to lesser extent, of alkali metals. The deposit formation process in the grate was found to be caused by the mixing of hematite pellet fines and unburnt carbon from the coal ash. The hematite was reduced to wustite by the presence of residual carbon, which generated low melting phases forming sticky deposits on the grate walls.

1. Introduction

Pellets are produced from the agglomeration of crushed iron ore fines using moisture and binder [1]. The mixture of high basicity sinter and acid oxidized pellets is perceived as an ideal burden structure for iron-making in blast furnace [1,2]. The production of pellets has several advantages, such as high quality, strong production ability and excellent metallurgical properties [3,4]. In China, more than half of the iron-ore pellet production is carried out by the grate-kiln process. In addition, coal, oil and natural gas are usually used to support high temperature during the iron-ore pellet production during the grate-kiln process. Particularly, pulverized coal was mainly used as the preferred fuel in China due to its abundance occurrence.

However, slagging deposits are frequently stuck to the refractory walls of the grate and kiln during the iron-ore pellet production, which interrupts the normal production and decreases the production efficiency [5]. Since coal is used as the fuel, the deposits are usually found in preheating zone of the grate and on the inside wall of the kiln, which indicates that it is the ash in the coal that is triggering the slag formation. It is also well known that the deposition of particles is frequently observed during the combustion of pulverized coal in coal-fired power plants and coal fired boilers [6–10]. However, the process of deposit formation in the pellet production is more complicated due to the reason that the particles from pellet powder are mixed with the flying coal ash, resulting in the deposit formation in the grate-kiln process. When the flying ash particles hit the refractory walls, inertial impaction and condensation, as well as the chemical reactions, lead to the deposits formation [6,11]. Furthermore, compared with the oil firing, the deposition rate was increased during the combustion of coal [5]. Similarly, after the fuel (used in the plant) was changed from oil to coal, the deposition significantly increased during the process carried out at Kobe Steel Ltd., Japan [12].

Previous researchers have focused on the deposit formation in a kiln. Their works showed that the major phases of deposit formation in a pellet rotary kiln are hematite, silicate and some limited glass phase while they are mainly composed of Al_2O_3, SiO_2, CaO, K_2O and Na_2O [13–15]. Apparently, with further increase in temperature, deposits were formed more rapidly, and were sintered and densified to a greater extent [16]. Stjernberg et al. [5] studied the deposits in a grate-kiln process, in which the hematite particles were embedded in a bonding phase, as well as Si, Al, Fe, Ca, and O, formed the deposits. A previous study [17] has investigated the effects of coal combustion on deposit formation in the kiln and indicated that the unburnt coal caused and aggravated the deposit formation in the kiln. However, the deposit formation mechanism is not fully understood in the grate for coal-based iron ore pellet plant. Therefore, it is essential to investigate the deposit formation process in the grate during the production of iron-ore pellets.

In the present work, the formation mechanism of deposits in the grate during the production of coal-based iron-ore pellets has been

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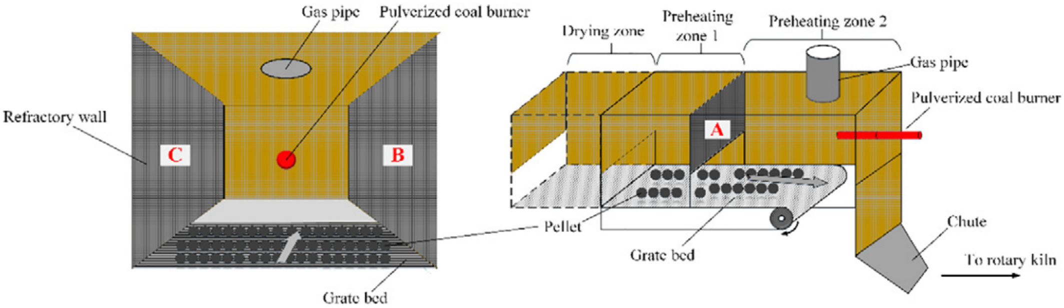

Fig. 1. Schematic diagram of the deposits in the grate.

studied. Chemical compositions, phase constitution, microstructure of deposit samples of the pulverized coal were determined using chemical analysis methods, XRD and SEM, respectively. Finally, the mechanism of deposit formation in the preheating zone was analyzed and summarized. This study aim not only to help understand better the formation mechanism of deposits in a better way, but also to aid the producers of iron-ore pellets to take reasonable measures to reduce the tendency of deposit formation.

2. Material and methods

2.1. Description of the grate

The grate-kiln plant investigated in the present study was a Chinese hematite pellet plant. The grate furnace has 56 m length and 4.5 m width. The wet green pellets were loaded on the traveling grate, which brought them through the different drying zones and preheating zones. The length of preheating zone 2 is 21 m. The temperature of the preheating zone 2 was measured at the end of the grate with values close to 1100 °C. In order to keep the sufficiently high temperature of the preheating zone 2, the combustion of the pulverized coal in the grate and a coal burner was adopted at the end of the grate (Fig. 1).

2.2. Materials

The materials were sampled from a hematite pellet plant in China. Hematite was used to pelletize, whose total iron grade was 65.47% and FeO content was 4.58%. The chemical composition of preheated pellet was displayed in Table 1 and the chemical composition of coal ash was listed in Table 2. As listed in Table 3, the proximate analysis of coal shows as follows: fixed carbon: 65.48% (air-dried basis), volatile matter: 17.95% (dry and ash-free basis), ash: 13.43% (air-dried basis). Besides, Table 4 shows the ash flow temperature (AFT) of the pulverized coal.

2.3. Methods

2.3.1. Chemical analysis

The chemical compositions of preheated pellet and deposit samples were determined using chemical analysis methods as described in the Chinese standards [18]. The chemical composition of coal ash and the proximate analysis of the coal were conducted according to GB/T 1574-2007 [19] and GB/T 212-2008 [20], respectively.

Table 1
Chemical composition of preheated pellet (wt%) [17].

Total Fe	FeO	SiO_2	CaO	Al_2O_3	MgO	K_2O	Na_2O	S
64.17	Trace	3.89	1.76	1.50	0.62	0.11	0.14	0.075

2.3.2. Scanning electron microscopy (SEM)

The deposit sample was characterized using a scanning electron microscopy (SEM, Quanta-200 FEI) coupled with an energy dispersive spectra analyzer (EDS, Ametek, Inc., Paoli, CO).

2.3.3. X-ray diffraction (XRD)

Phase composition of deposit sample was determined by an X-ray diffraction (XRD) using a diffractometer (RIGAKUD/Max 2500, Japan).

2.3.4. Thermodynamic software

FactSage (Thermfact/CRCT (Montreal, Canada) and GTT-Technologies (Aachen, Germany)) is a thermodynamic software and database package, which has been widely used in chemical engineering, metallurgical engineering and mineral processing engineering [21]. FactSage (version 7.0) was adopted in this study to obtain the phase diagrams. Two databases (FactPS, FToxid) were used, while the phases (such as, FToxid-SlagA) were selected. The thermodynamic results were used to analyze the formation mechanism of the deposits in the grate.

3. Results

3.1. View of the deposits

Several previous researches [5–10] have indicated that the deposition can be formed on many places during the combustion of pulverized coal. In the study, deposits were found on the walls (walls A, B, and C as shown in Fig. 1) of the grate, whereas a pulverized coal burner was used to ensure sufficiently high preheating temperature in the grate. Fig. 1 shows the relative positional relationship between the direction of flame and the deposits in the grate. As illustrated in Fig. 1, it can be seen that the deposits were formed on the walls which were located in the front and on the sides of the coal burner. Furthermore, it was also observed that the deposits were accumulated along the flow direction of the fire flame in the production site. It can be seen that the deposit samples in the walls tilted towards the gas flow direction. Thus, according to the positions and growing shapes of the deposits, it can be inferred that the deposit formation had a significant relationship with the combustion of pulverized coal.

Fig. 2 shows the outside view of a deposit sample on the wall of the grate. It can be seen that the color of the deposit was grayish-black, while some particles were also observed. Moreover, the deposit was loose and had a porous structure rather than being very dense. Additionally, some previous studies have indicated that the inertial impaction was the driving force for the deposition in the preheating zone

Table 2
Chemical composition of coal ash (wt%) [17].

Total Fe	SiO_2	CaO	Al_2O_3	MgO	K_2O	Na_2O	S
3.80	50.64	7.20	26.31	1.10	1.00	1.06	1.22