



## Research article

## Initial stage of deposit formation process in a coal fired grate-rotary kiln for iron ore pellet production

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## ABSTRACT

Serious deposits in the grate-kiln plant for iron ore pellet production can decline pellets quality and reduce production efficiency. The initial stage of deposit formation is crucial for adhesion and growth of deposit on refractories in the kiln. In this study, the simulated experiments of FeO formation indicated that the high FeO content decreased with increasing the roasting time. The effects of combustion efficiency of pulverized coal and Na<sub>2</sub>O amount on the adhesion on the refractory bricks were experimentally studied using an evaluated method. The results showed that the adhesion on the refractory bricks increased with decreasing the combustion efficiency of pulverized coal and increasing the Na<sub>2</sub>O content in the deposits. Finally, the mechanism of deposit formation mainly on the center-entrance area in the kiln was summarized as follows: the pulverized pellet powder and coal ash with unburnt carbon fell into the pores and cracks of the refractory bricks in the kiln. The unburnt carbon and alkali metal chemically reacted with the pellet powder and contributed to the formation of low-melting-point phases (fayalite, silicate), then the generated low melting point phases plus the chemical reactions between the deposits and refractory bricks caused the adhesion of deposits on the refractory bricks. The deposits grew and became thicker as the continuous effects of the above process.

## 1. Introduction

A large quantity of iron ore concentrate obtained by separation and beneficiation process must be agglomerated through sintering and pelletization before ironmaking [1]. Iron ore pellets play an important role in the raw materials for ironmaking [2]. In China, the grate-rotary kiln process is widely adopted to produce iron ore pellets [3]. However, deposits are frequently found on grate wall, kiln and other high-temperature device parts, which decline pellets quality, reduce production efficiency and increase production cost [4,5]. In general, coal, natural gas and oil are used as fuel to provide required high temperatures for iron ore pellets production. Especially, deposit phenomenon becomes more serious when fuel was changed from oil to coal.

At present, it is essential to investigate the deposit formation mechanism to make the grate-kiln process successfully to produce the iron ore pellets. Many researchers have focused on this problem and they increase the understandings about it [6–10]. The deposit formation mechanism in a grate-kiln plant was investigated through analyzing the characteristics of gas particles and deposits [8,9]. Furthermore, it is well accepted that deposits can frequently be observed in the kiln when

using pulverized coal as the fuel [7,11]. The deposit formation mechanism in a pulverized coal-fired grate-rotary kiln is very complicated due to deposit comes from both iron ore pellet powder and flying coal ash. Zhong et al. [7] showed that pure pellet powder was difficult to form deposits due to its insufficient Fe<sub>2</sub>O<sub>3</sub> recrystallization, but their weak bonding could be intensified by coal ash. Also, some previous works showed that the major phases of deposits formed in a rotary kiln plant for iron ore pellet production were hematite, silicate and some limited glass phases [12,13]. In addition, increasing temperature can make the deposit form rapidly [14]. Besides, deposits can frequently be found in coal-fired power plants and boilers, and the investigations indicated the coal combustion has a significant influence on the deposit formation [15–20]. Furthermore, the unburned carbon can be frequently found in fly ash due to inefficient coal combustion [21–23] and probably has a significant influence on the deposit formation. Our previous papers [13,24] reported that the uncompleted combustion of pulverized coal had significant effects on the deposit formation on the refractory bricks in the grate-kiln plant. In Ref. [13], we summarized the deposit formation mechanism in the grate based on the characterizations of deposit samples from the refractory bricks in the grate. In

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**Table 1**  
Chemical compositions of raw materials (wt%) [24].

Materials	Chemical composition/wt%								
	Total Fe	FeO	SiO <sub>2</sub>	CaO	Al <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	S
Preheated pellet	64.17	–	3.89	1.76	1.50	0.62	0.11	0.14	0.075
Deposit sample 5#	61.93	–	5.91	2.41	2.25	1.37	0.089	0.16	0.007
Coal ash	3.80	–	50.64	7.20	26.31	1.10	1.00	1.06	1.22

Ref. [24], we mainly focused on the effects of carbon content and roasting temperature on the adhesion on the refractory bricks, as well related phase diagrams and deposit formation mechanism were proposed. However, due to trace FeO in the deposit samples, we could not find the FeO in the deposit samples; this might be as a result of strong oxidization atmosphere in the grate and kiln so that probably formed FeO was oxidized after more than one-month continuous production. The formation of FeO and effect of corresponding coal combustion efficiency during the deposit formation process is crucial for the deposits formation. Furthermore, the presence of alkali metal also should be considered during the deposit formation process. However, those were not investigated in previous papers, it is therefore essential to make the proposed mechanisms more comprehensive and convincing, and to obtain a better understanding about deposit formation in a coal-fired kiln plant for iron ore pellet production.

In addition, it must be clear that the deposit formation process is a continuous and long process. Thus it is difficult to take the typical deposit samples from the kiln during the iron ore pellets production. In this study, the on-site deposit samples were analyzed and the deposit formation process was studied with an aim to reveal the formation mechanism of deposit. The mineralogical phase composition, microstructure and elemental distributions of the deposit samples were analyzed by X-ray diffraction (XRD) and scanning electron microscopy with energy dispersive spectroscopy (SEM-EDS) techniques. The formation of FeO in the initial stage of deposit formation and the effects of corresponding coal combustion efficiency, as well as the amount of alkali metal on the adhesion on the refractory bricks, were experimentally investigated. Finally, the comprehensive deposit formation process was summarized. Our findings can provide clearer understanding about the deposit formation in coal-fired grate-kiln plants, and based on our findings some corresponding effectively measures can be taken to control the deposit formation during the iron ore production.

## 2. Materials and experimental methods

### 2.1. Materials

The preheated pellet powder, deposit sample and coal were provided by an iron ore pellet plant in China. In the grate-kiln plant, the

**Table 2**  
Chemical composition of refractory brick (wt%) [24].

Total Fe	SiO <sub>2</sub>	CaO	Al <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	TiO <sub>2</sub>
2.76	13.79	1.46	63.55	0.13	0.53	3.27

**Table 3**  
Proximate analysis of coal and pure coal ash (%).

	M <sub>ad</sub> ,%	A <sub>ad</sub> ,%	V <sub>ad</sub> ,%	FC <sub>ad</sub> ,%
Pulverized coal	3.14	13.43	17.95	65.48
Pure coal ash (PCA)	0.13	99.51	0.28	0.08
removed volatile pulverized coal (RVC)	0.10	16.43	0.88	82.59

grate has a length of 56 m and a width of 4.5 m, the diameter of the kiln is 6.1 m and its length is 40 m. The required roasting temperature in the rotary kiln to obtain qualified roasted pellets is about 1280 °C in this grate-kiln plant and it is closer to the temperature near the walls at the refractory linings. It should be mentioned that the wall temperature and gas temperature is difficult to be measured during the iron ore pellet production. Moreover, according to a simulation of temperature distribution in a coal-fired kiln by Fan et al. [25], the gas temperature of similar location of deposit sample removed from in this study was about 1300 °C. In the preheating zone II of the grate and rotary kiln, to obtain a sufficiently high temperature, a pulverized coal was adopted as the fuel to provide the high temperature. Unfortunately, the serious deposits were found in the rotary kiln and on the walls of preheating zone II in the grate. Table 1 shows the chemical compositions of the preheated pellet powder, on-site deposit sample and pulverized coal ash. It can be seen that the total iron of deposit sample is lower than the preheated pellet, but higher than that of the coal ash. The contents of SiO<sub>2</sub>, CaO and Al<sub>2</sub>O<sub>3</sub> of the deposit sample are higher than that of the preheated pellet. In addition, the chemical composition of the refractory brick is listed in Table 2. It indicates that the refractory brick belongs to high-alumina brick. Furthermore, the proximate analysis of pulverized coal is shown in Table 3. In this study, the coal ash was prepared through roasting the pulverized coal in a muffle furnace at 850 °C for more than 4 h under air atmosphere. According to the proximate analysis of coal ash shown in Table 3, the fixed carbon of the coal ash is close to zero, which proves that the combustion of pulverized coal is completed.

### 2.2. Experimental methods

#### 2.2.1. Preparation of simulated deposit samples

In this study, the pure coal ash (PCA) and the removed volatile pulverized coal (RVC) were prepared for following experiments. According to a Chinese Standard GB/T 212-2008 (proximate analysis of coal) [26], the roasting temperature is 815 ± 10 °C for determination of coal ash. Thus, the pure coal ash (PCA) was prepared by burning the pulverized coal in a muffle furnace at 850 °C for more than 4 h under air atmosphere. According to the proximate analysis of pure coal (Table 3), the fixed carbon of the coal ash is close to zero, which proves that the coal combustion is completed. In addition, the removed volatile pulverized coal (RVC) was prepared as following steps: the pulverized coal (30 g) was placed in an alumina crucible with a cap and then roasted in a muffle furnace at 920 °C for 40 min under a high purity nitrogen atmosphere in order to remove the volatile. The proximate analysis of

**Table 4**  
Preparation parameters for coal ash samples with different combustion efficiency.

Coal ash sample no.	Designed combustion efficiency/%	PCA/wt%	RVC/wt%
CA-80%	80	40.38	59.62
CA-85%	85	48.99	51.01
CA-90%	90	60.39	39.61
CA-95%	95	76.32	23.68
CA-100%	100	100	0

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