The Effect of Temperature and Roasting Time on the Conversion of Zinc Ferrite to Zinc Oxide in the Electric Arc Furnace Dust

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Abstract. The dust of electric arc furnaces (EAF-dust) contains significant amounts of zinc in the form of various chemical compounds. Therefore, dust can be used as a raw material for zinc extraction. EAF-dust containing 20 wt.% Zn has been studied. The effect of dust roasting with CaO and Na₂CO₃ additives on the degree of conversion of ZnFe₂O₄ to ZnO was studied experimentally. The effect of the roasting temperature of 700, 850 and 1000 °C and the roasting duration of 1, 2 and 3 hours were established. CaO and Na₂CO₃ additives in dust contribute to the destruction of ZnFe₂O₄ due to the formation of Ca₂Fe₂O₅ and NaFeO₂. After treatment, zinc is presented in the form of acid-soluble zinc oxide. The content of acid-soluble zinc increases from 25% in the initial dust to 97–98% in the roasting product (“cinder”) under optimal roasting conditions.

1. Introduction

Zinc is widely used for hot and electrolytic galvanizing of steel products. Up to 80% of zinc produced in the Russian Federation is used in galvanizing processes [1]. World consumption of zinc increases annually by 1.1–1.5% [3]. A part of galvanized metal scrap is melted in electric arc furnaces. During smelting, zinc evaporates and is oxidized by atmospheric oxygen to form various solid oxide compounds of zinc. 15–25 kg of zinc-containing dust is formed per ton of steel produced [8, 9], up to 90% of the initial zinc goes into dust [4]. EAF-dust contains up to 20 wt.% zinc [5–7]. Recycling of dust by remelting method does not apply due to the harmful effect of zinc on the furnace lining [18]. In different countries, including the Russian Federation, some of the dust is stored at specialized landfills, and some of the dust is processed through using zinc sublimation technology using carbon, for example, the Waelz-process [10–15]. Products of the Waelz-process (waelz-oxide) are processed by leaching in sulfuric acid, after the removal of halogens [17, 25, 26]. Zinc is extracted from the sulphate solution by electrolysis. Direct dust leaching is often not carried out due to the presence of zinc ferrite ZnFe₂O₄ in dust, about 60% of zinc in dust is part of zinc ferrite [5–7, 16]. Alkaline treatment of dust has an advantage over reduction technology, since the use of expensive carbon materials (for example, coke) is not required. Leaching EAF-dust in alkaline solutions is possible, but the limiting factor is the presence of zinc ferrite in dust [18–23].

High-temperature roasting of dust with CaO and Na₂CO₃ additives is one of the options for increasing the proportion of acid-soluble zinc (in the form of ZnO) in dust. CaO and Na₂CO₃ contribute to the destruction of ZnFe₂O₄ due to the formation of Ca₂Fe₂O₅ and NaFeO₂. Previously, we found the optimal amount of CaO and Na₂CO₃ additives to the initial dust for roasting [2].
In this study, the effect of temperature and roasting time on the conversion of zinc ferrite to zinc oxide was studied overview.

2. Experimental

2.1. Materials and apparatuses
The chemical composition of EAF-dust is given in Table 1. The following reagents were used as additives: calcined calcium oxide GOST 8677-79, soda ash GOST 5100-85. The roasting was carried out in a muffle furnace in aerial environment. The phase composition of the samples was determined by the method of X-ray analysis (diffractometer Rigaku Ultima IV, Nanotechnology R&E Centre, South Ural State University [24]).

| Element       | Content (wt.%) | Element       | Content (wt.%) | Element       | Content (wt.%) |
|---------------|---------------|---------------|---------------|---------------|---------------|
| Zn (total)    | 20.41         | Al            | 0.5           | Na            | 1.98          |
| Zn (in ZnO)   | 5.04          | Fe            | 24.18         | Cl            | 1.8           |
| Pb            | 1.43          | Ca            | 7.87          | F             | 0.078         |

2.2. Procedures
The composition of the mixture for roasting, in grams, is 50.0 dust; 6.28 CaO and 17.79 Na$_2$CO$_3$. The components were thoroughly mixed in a mechanical mixer. The mixture in the form of a pyramid was placed on the surface of the refractory substrate. Periclase-chromite brick was used as a substrate. The roasting of the mixture was carried out at a temperature of 700, 850 and 1000 °C for three hours. The pyramids retained their shape at a temperature of 700 °C. The pyramids softened and turned into an oblate cylinder form at 850 and 1000 °C. The change in the shape of the pyramids is associated with the melting of Na$_2$CO$_3$. The softening effect of the charge must be considered in the technological process. At a constant temperature of 1000 °C, roasting was performed using an exposure of 1, 2, and 3 hours.

The roasting products ("cinder") were investigated for the content of total zinc and acid-soluble zinc in the form of ZnO. The fraction of soluble zinc $\varepsilon_{Zn}$ (in %) was calculated from equation (Eq. 1):

$$
\varepsilon_{Zn} = \left( \frac{\%Zn_{ZnO}^{cinder}}{\%Zn_{ZnO}^{total}} \right) \times 100 \%,
$$

where $\%Zn_{ZnO}^{cinder}$ is the zinc concentration in zinc oxide, wt.%; $\%Zn_{ZnO}^{total}$ is the total concentration of zinc in cinder, wt.%. The transition degree of zinc $\gamma_{Zn}$ (in %) from zinc ferrite to zinc oxide was calculated from equation (Eq. 2):

$$
\gamma_{Zn} = \left( 1 - \left( \frac{\%Zn_{ZnO}^{cinder}}{\%Zn_{ZnO}^{total}} - \frac{\%Zn_{ZnO}^{cinder}}{\%Zn_{ZnO}^{dust}} \right) \frac{m_{cinder}}{m_{dust}} \right) \times 100 \%,
$$

where $\%Zn_{ZnO}^{dust}$ is the total concentration of zinc in the initial dust, wt.%; $\%Zn_{ZnO}^{dust}$ is the zinc concentration in zinc oxide in the initial dust, wt.%; $m_{dust}$ is the mass of initial dust, g; $m_{cinder}$ is the mass of cinder, g.

3. Results and Discussion
The X-ray diffraction patterns of the four samples (initial EAF-dust and cinder after treatment at 700, 850 and 1000 °C for 3 hours) are given as an example in Figure.

With increasing temperature, the intensity of the ZnFe$_2$O$_4$ reflections consistently decreases until disappearing, and the reflex intensity of ZnO, Ca$_3$Fe$_2$O$_5$ and NaFeO$_2$ increases. The experimental results are
in complete agreement with the results of thermodynamic analysis on cinder composition changes during heating, which were established earlier [2].

The effect of temperature and roasting duration on the increase in the content of acid-soluble zinc are given in the Table 2. The content of acid-soluble zinc increases from 25 % in the initial dust to 97–98 % in the cinder under optimal roasting conditions (1000 °C, the roasting time of 3 hours).

Figure 1. The X-ray diffraction patterns of the initial EAF-dust and cinder.
Table 2. The influence of temperature and the roasting time on the transition degree of zinc $\gamma_{Zn}$ and on the fraction of soluble zinc $\varepsilon_{Zn}$.

| Temperature, [$^\circ$C] | Roasting time, [hour] | $\gamma_{Zn}$, [%] | $\varepsilon_{Zn}$, [%] |
|--------------------------|-----------------------|-------------------|---------------------|
| Initial EAF-dust         | –                     | –                 | 24.7                |
| 700                      | 3                     | 42.4              | 50.6                |
| 850                      | 3                     | 91.6              | 92.8                |
| **1000**                 | **3**                 | **97.5**          | **97.9**            |
| 1000                     | 2                     | 89.2              | 90.8                |
| 1000                     | 1                     | 83.9              | 86.2                |

4. Summary
The effect of dust roasting with CaO and Na2CO3 additives on the degree of conversion of ZnFe2O4 to ZnO was studied experimentally. The effect of the roasting temperature of 700, 850 and 1000 °C and the roasting duration of 1, 2 and 3 hours were established. The content of acid-soluble zinc increases from 25 % in the initial dust to 97–98 % in the cinder under optimal roasting conditions (1000 °C, the roasting time of 3 hours).

The roasting product ("cinder") with a zinc as zinc oxide can be used in alkaline leaching to produce zinc pregnant solution.

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