Characterization of Steelmaking Zinc-Containing Converter Dust

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Abstract. Due to the increasing use of scrap galvanized steel in converter process, the content of zinc in converter dust is rising gradually as a result of zinc enrichment and accumulation, which will cause problems to dust recycling from long-term production stability and safety. The aim of this study was to reveal the chemical, physical, mineralogical and morphological characteristics of zinc-containing converter dust. The study shows that the concentration of Fe, Ca, Zn is 52.43~54.25%, 5.97~6.09%, 3.60~3.73% respectively. The phases such as Fe3O4, Fe2O3, FeO, ZnFe2O4, ZnO and C were detected through XRD analysis. Granulometric analysis indicated that, the particle size distribution is very concentrated and almost 80% of particles are finer than 1μm. Further researches on integrated utilization process are necessary in order to develop effective method to recycle zinc-containing converter dust.

1. Introduction
Metallurgy dusts are the main solid wastes in steelmaking process. The total quantity of dusts in a steelmaking plant is generally 8%-12% of steel production. Converter dust is generated in converter steelmaking process, accounting for a quarter of the total amount of dusts and sludges in a steelmaking plant. The converter dust is normally returned to the sintering process as a smelting ingredient [1, 2]. In recent years, more and more galvanized scraps are used in steelmaking process. Due to low boiling point of zinc element and higher vapor pressure in converter process, most of zinc from scraps is carried out with other particles into the off-gas cleaning system, and collected as dusts or sludges subsequently, consequently, zinc content in the converter dust increases gradually. If the zinc-containing converter dust is reused directly as usual, zinc would be to circulated and enriched through the whole system continuously, as a result, the zinc load on the blast furnace will exceed the limit, which would do harm to the stability and safety of long-term production eventually [3]. Therefore, when the zinc load approaches the limit, the zinc-containing converter dusts and sludges cannot be reused directly any more, they can only be stored temporarily which might have negative impact on the environment [4].
A flow sheet for off-gas cleaning system is shown in Figure 1. The gas generated from the converter enters the evaporative cooling tower via cooling flue, in which the gas temperature is cooled rapidly down to 180°C by spraying water to avoid the explosion temperature range. Afterwards, converter dust is intercepted and collected by electrostatic precipitators, and the flue gas is cooled again through gas cooling tower. Cleaned and qualified gas enters the gas tank for storage. The combustible part of the flue gas will be ignited and burned before being released to the atmosphere via discharge chimney [5, 6].

The present work is to deal with the characterization and utilization of zinc-containing converter dust. The aim of this study was to perform a detailed investigation of chemical, physical, mineralogical and morphological characteristics of converter dust, which can provide a basis to develop rational technologies for utilization. The characterization of converter dust was carried out by using inductively coupled plasma (ICP), Scanning electron microscopy (SEM) with energy-dispersive spectroscopy (EDS), X-ray diffraction (XRD) and Granulometric analysis.

![Figure 1. Off-gas cleaning system flow sheet](image)

2. Experiments
The converter dust samples were dried for 2 h at 105°C and stored in a desiccator filled with silica gel. The chemical composition of converter dust was determined by inductively coupled plasma (ICP) using Agilent 5110. The crystalline phases of the converter dust were determined by X-ray diffraction (XRD) using Bruker Phase D2. The scan ranges from 10 to 80° 2θ using a step size of 0.02° 2θ and a step time of 0.02s per step. The XRD analyses were done under the conditions of 30kV and 10 mA. Scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDS) measurements using Phenom LE were performed to get information on the structure, morphology and chemical composition of converter dust particles. The granulometric analysis of converter dust was measured using Malvern 2000.

3. Results and Discussions
3.1. Chemical Composition
The result of the chemical analysis of converter dust samples in this study is presented in Table 1. It is clear that the chemical composition of the three samples is almost the same. The results in Table 1 shows that Fe and Ca are the major elements in converter dust of which contents are 52.43~54.25% and 5.97~6.09% respectively. The content of zinc is 3.60~3.73% which is higher than that of usual converter dust. Other elements such as K, Mg, Na, Cr, Mn, Al exhibit relatively low concentrations less than 1%.
Table 1. Chemical Composition of converter dust

| Element | Fe   | Ca   | Zn   | K    | Mg   | Na   | Cr    | Mn    | Al   |
|---------|------|------|------|------|------|------|-------|-------|------|
| sample1 | 52.43| 5.97 | 3.60 | 0.397| 0.974| 0.031| 0.586 | 0.037 |      |
| sample2 | 53.89| 5.99 | 3.63 | 0.423| 1.140| 0.029| 0.597 | 0.054 |      |
| sample3 | 54.25| 6.09 | 3.73 | 0.460| 0.966| 0.031| 0.609 | 0.038 |      |

3.2. Mineralogical Analysis
The main mineralogical composition of converter dust was determined by XRD (Figure.2). The major phases were identified: magnetite (Fe₃O₄), hematite (Fe₂O₃), wuestite (FeO). Zinc in the examined sample is in the forms of zinc ferrite (ZnFe₂O₄) and zinc oxide (ZnO). The phases of other elements such as alkaline elements were not identified in this analysis due to their low content which is hardly detectable by XRD.

![Figure 2. X-ray diffraction pattern for converter dust](image)

3.3. SEM-EDS Analysis
Scanning electron microscopy with an energy dispersive spectrometer was performed to gain further information on morphology of converter dust. Figure.3 shows the scanning electron micrograph of converter dust particles. It is obvious that most of the converter dust particles appear as spherical fine-grained particles which are almost submicronic and smaller than 1μm. Most of the fine particles are present as agglomerated morphology.

![Figure 3. Scanning electron micrograph (magnification 50000x) of converter dust particles](image)
Figure 4. ED’s distribution maps of Fe, O, Zn, Ca, Mg, Al, Si, Cl and K elements in the converter dust sample.

Figure 4 shows EDS distribution maps of Fe, O, Zn, Ca, Mg, Al, Si, Cl and K elements in order to clarify their distribution in converter dust samples. The EDS distribution maps show that the distribution of iron is consistent with the oxygen distribution, indicating that they might combine as a compound. The distribution of zinc is dispersed and uniform, which is neither concentrated in large particles nor small particles [7]. The distribution of zinc is almost consistent with the iron distribution. It is speculated that the form of zinc might be zinc ferrite or the form of solid solution which was occupied by zinc in the iron oxide lattice. Due to the low reactivity of zinc ferrite, it will bring more difficulties in treatment and reuse of zinc-containing converter dust [8].

3.4. Granulometric Analysis

The granulometric analysis of converter dust is presented in Figure 5 and Figure 6. There are three major grain-size fractions in this sample, and the particle size $d$ (0.1), $d$ (0.5) and $d$ (0.9) is 0.136μm, 0.201μm, 1.986μm respectively. The cumulative curve shows that almost 80% of particles are finer than 1μm. The granulometric analysis results indicate that physical separation methods, such as magnetic or gravity separation technologies are difficult to achieve the separation purpose. However, due to fine particle sizes, chemical reactions could be fast and efficient, which might be favorable to zinc separation reactions.

Figure 5. The distribution curve of converter dust
The converter dust samples were wet sieved and separated according to the particle size. The zinc content and yield for different particle sizes were measured, and results were presented in Figure 7. It shows that more than 50% particles are finer than 2000 mesh. Particles finer than 2000 mesh may exist, but it is hard to separate finer particles further by wet sieving. The zinc content for different size particles was shown in Figure 7 (b). The result shows the finer the particle size, the higher the zinc content, which is in agreement with the mechanism of zinc-containing particles formation. The zinc vapor is formed firstly, then zinc element will condense on the surface of other particles, or react with the iron oxide particles on the surface [8, 9]. Therefore, there is a negative correlation between zinc content and particle size. The recovery process of blast furnace dust and sludge is developed based on this feature, for instance, hydro-cyclones can be used to harvest finer particles with higher zinc content to enrich and recover zinc resource [10]. However, the particle size distribution of zinc-containing converter dust is too narrow and concentrated, zinc is evenly distributed among all dust particles, as a result, zinc cannot be separated and enriched effectively even with the cascade combination of hydro-cyclones [11, 12].

**Figure 6.** The cumulative curve of converter dust

The present results give a detailed characterization of zinc-containing converter dust in order to help determine an appropriate recovering technology. The major elements are Fe and Ca which are present with 52.43~54.25% and 5.97~6.09% in converter dust respectively. As the direct consequence of using more scrap galvanized steel, the content of zinc is 3.60~3.73%, which is higher than that of
usual converter dust. Phases such as \( \text{Fe}_3\text{O}_4, \text{Fe}_2\text{O}_3, \text{FeO}, \text{ZnFe}_2\text{O}_4, \text{ZnO} \) and C were detected via XRD analysis. SEM-EDS analysis indicate that the distribution of zinc is dispersed and almost consistent with the iron distribution. The zinc-containing converter dust has a homogenous distribution of particles, where 80% particles are finer than 1\( \mu \text{m} \).

Based on achieved results, most of zinc in converter dust are combined with iron oxide in the form of compound, physical separation technologies are not suitable to separate and enrich zinc from converter dust. Due to relative low content of zinc, pyrometallurgy and hydrometallurgical methods are not the most optimum treatment process. Further researches on integrated utilization process are necessary to solve zinc-containing converter dust reuse problems.

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