The pyrometallurgical recovery of zinc from electric arc furnace dust (EAFD) with active carbon

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Abstract. The reduction of minor impurities (e.g., Ferrite, Magnesium, Lead, Chromium) from Zinc rich-EAFD with active carbon addition was investigated at temperature between 900-1300 °C. The result was powder with higher zinc content which then analysed by X-ray fluorescence spectroscopy (XRF), X-ray diffraction (XRD) and scanning electron microscope (SEM) equipped with X-Ray energy dispersive spectrometry (EDS). The thermogravimetry (TG) and differential thermal analysis (DTA) of EAFD and carbon mixture was conducted previously to grasp the temperature of thermic reaction of mixture. Recovery of 90wt% zinc from EAFD available was achieved up to 99.2wt% after the pyrometallurgy process at temperature 900 °C in atmosphere pressure while the extension of the time corresponds to the amount of recovered zinc dross.

1. Introduction

The prodigious expansion of steel manufacture grows rapidly because the advancement of electric arc furnace (EAF) technology. EAF technology has contributed to more than 25% of the world’s total crude steel production [1]. In typical EAF operation, approximately 10-20 kg dust, called EAFD is produced per ton of steel [2]. Dust formation essentially associated to the thermic process of the charged material that includes scrap materials, lime, dolomitic lime and carbon which then will determine on the quality of steel product [3]. When the scrap is melted in the EAF, most of the zinc from the steel scrap ends up in the dust and fume due to its low solubility in molten steel and slag, beside the zinc vapour pressure is higher than iron vapour pressure at steel production temperature. Iron and other slag particles in an oxidizing atmosphere are always found as impurity in the released zinc particles. Subsequently, the forming compounds like ZnO and ZnFe₂O₄[4] is ensued on top of the furnace and flows through the ventilation system. Thereafter, all evaporated material are collected in the dusting system originating the EAFD [5,12].

Generally, EAFD contains two major elements zinc and iron [6,7], nevertheless EAFD is always mixed with other minor impurities which are categorized as harmful heavy metal, such as Pb, Cr and Cd [8]. Hence, EAFD is classified hazardous waste that difficult to store and transport [9]. EAFD requires further treatment to be released in the environment, because it contains hazardous, leachable...
elements [10]. The accumulation of EAFD in landfilling area is not only causing harmful effect to plant and animal as well as human environment. However, EAFD has several valuable elements such as zinc oxide and iron, thereof many EAFD recovery has been studied and developed.

There are two method of metal recovering that has been widely used for purifying EAFD, the first is the leaching method [13]. This method involves chemical reaction between leachable element in EAFD with acid solution. Although this method is less energy required, the process results another waste [14]. The second is treating the EAFD with pyrometallurgy process [4-10]. The pyrometallurgy process is considered as the best method of recovering the zinc oxide from EAFD though it requires a lot of thermal energy because this method does not result any more waste material. The purpose of this research paper is to present the results of laboratory scale pyrometallurgy process established for recovering zinc oxide from EAFD. Information regarding physical and chemical properties of recovered zinc oxide were studied by XRD, XRF and SEM-EDX.

2. Experimental

2.1. Materials
EAFD from steelmaking industry, was in form of lump with dark blue colour. The concentration of elements in the EAFD is shown in Table 1. The content of zinc metal appertains to 90 wt% and the remaining were considered as impurities. The reductant material chosen for recovering the zinc was active carbon which was synthesized in laboratory of research centre for physics Indonesian institute of sciences.

| Element | Zn | Fe | Mg | Al | Ca | S | Cl | K | Ba | Other |
|---------|----|----|----|----|----|---|----|---|----|--------|
| wt%     | 90 | 4.09 | 2.53 | 0.49 | 0.19 | 0.1 | 0.09 | 0.08 | 0.07 | <0.05  |

Other: Si, P, Ti, Cr, Sr, Sn

2.2. Methods
The mixture of EAFD and active carbon were prepared using ball milling method. The compositions of the EAFD and active carbon were varied 7:1 and 3:1. Each 100 gram of mixture was dissolved with 200 ml demineralized water and milled in planetary ball mill for 40 minutes. The result was slurry mixture which then filtered to reduce the water content. The less water slurry then dried in oven at 100 °C for 24 hours. The drying process was aimed to get the lowest possible moisture, since hydrogen in the furnace off-gas could have a detrimental effect on the efficiency of zinc condensation [15]. The dried mixture was then heated in tube furnace at 1200 °C in atmospheric pressure for 2.5 hours. The temperature and heating duration was chosen based on the preliminary experiment to achieve both zinc oxide and residual material. The result and residual was then analysed by XRF, XRD and SEM-EDX.

The experimental system consisted of an alumina crucible inside an alumina tube were set into electric furnace 3.3 kW as shown in figure 1. The thermocouple was set close to sample to measure the real time temperature of the sample. One tip of the tube was connected to a low pressure blower while the other side was set longer in order to trap the zinc vapour crystalized on the lower temperature zone on the inside of the tube wall.
2.3. Thermodynamic Calculation

The reaction temperature involved in pyrometallurgical processing of EAFD are summarized by FactSage™ software version 7.0 in Table 2 [16]. The data shows that zinc oxide can be reduced into metallic forms at temperatures below 1000 °C, it assists recycling EAFD via pyrometallurgical process. After reduction, zinc, lead and cadmium will evaporate because of their high vapor pressures at the EAF operating temperature. The metal vapor can then be condensed, separated and recovered using a condenser system. Conversely, iron and chromium will be retained in the residue after thermal reduction. The result of thermodynamic analysis is shown in Fig 1.

Table 2. The reaction temperature in pyrometallurgical processing.

| No | Reaction | Reaction temperature (°C) |
|----|----------|--------------------------|
| 1  | ZnO(s) + C(s) = Zn(g) + CO(g)   | 955.88                   |
| 2  | ZnFe2O4(s) + C(s) = Zn(g) + FeO(s) + CO(g) | 791.35                   |
| 3  | PbO(s) + C(s) = Pb(s) + CO(g)     | 302.10                   |
| 4  | CuO(s) + C(s) = Cu(s) + CO(g)     | 15.18                    |
| 5  | MnO2(s) + C(s) = Mn(s) + CO(g)    | 1426.59                  |
| 6  | 3Fe2O3(s) + C(s) = 2Fe3O4(s) + CO(g) | 319.78                   |
| 7  | Fe3O4(s) + C(s) = 3FeO(s) + CO(g)  | 696.39                   |
| 8  | FeO(s) + C(s) = Fe(s) + CO(g)     | 726.41                   |
| 9  | ZnO(s) + Fe = Zn(g) + FeO(s)      | 1198.88                  |
| 10 | ZnO(s) + CO(g) = ZnO(g) + CO2(g) | 1317.90                  |
| 11 | ZnFe2O4(s) + CO(g) = ZnO(g) + FeO(s) + CO2(g) | 1330.96                 |
| 12 | MnO2(s) + 2C(s) = Mn(g) + CO2(g)  | 555.14                   |
| 13 | Fe3O4(s) + CO(g) = 3FeO(s) + CO2(g) | 637.10                  |
| 14 | FeO(s) + CO(g) = Fe(s) + CO2(g)   | 570.96                   |
| 15 | Cr2O3(s) + 3C(s) = Cr(s) + 3CO(g) | 192.42                   |
| 16 | CrO3(s) + 3CO(g) = Cr(s) + 3CO2(g) | 31151.28                |
| 17 | FeCr2O4(s) + C(s) = Fe + Cr2O3 + CO(g) | 1054.47                |
| 18 | CdO(s) + C(s) = Cd(s) + CO(g)    | 598.94                   |
| 19 | CdO(s) + CO(g) = Cd(s) + CO2(g)  | 434.80                   |
| 20 | (ZnO) + [C] = Zn(g) + CO(g)      | 864.92                   |
| 21 | (PbO) + [C] = Pb(g) + CO(g)      | 765.25                   |
| 22 | (FeO) + [C] = [Fe] + CO(g)       | 692.56                   |
| 23 | ZnFe2O4(s) + CaCl2(s) = CaFe2O4(s) + ZnCl2(g) | 1332.15                |
| 24 | Fe3O4 + 3CaCl2(s) = 2FeCl3(g) + 3CaO(s) | 2434.90                |
| 25 | ZnO(s) + CaCl2(s) = ZnCl2(g) + CaO(s) | 1468.48                |
3. Results and Discussion

Laboratory scale of pyrometallurgy devices for separating zinc from EAFD was successfully constructed. Recovery of 90 wt% zinc from EAFD available was achieved up to 99.2 wt% after the pyrometallurgy process at temperature 1200 °C in atmosphere pressure. The product was a condensed white powder adhere on the inside surface of alumina tube. The product was analysed by XRF, XRD and SEM. The result of XRF analysis are presented in Table 3.

| Metal Oxide | Content (ppm) |
|------------|--------------|
| ZnO        | 992000       |
| Al₂O₃      | 1440         |
| Fe₂O₃      | 979          |
| SiO₂       | 1550         |
| MgO        | 2020         |

Characteristics of the products was analysed using XRD, the result are shown in figure 2. The result confirm that the product is Zincite and Hydrozincite. Zincite is the mineral form of ZnO while the Hydrozincite is carbonite mineral consisting Zn₅(CO₃)₂(OH)₆.

![Diffractogram of the product](image)

**Figure 2.** Diffractogram of the product

SEM was also carried out to study the morphology characteristic of the product. The BSE image of the product is shown in figure 3. As shown in figure 3a, the particle seems agglomerate become a bigger particle. The bigger particle consists of random shaped smaller particle where the smaller particles are dominated by rod shape particle.
4. Conclusion
EAFD with 90% zinc content from steel industry have been given treatment in pyrometallurgy process with addition active carbon at 1200 °C. The result was solids with 99.2% zinc content in chemical form ZnO and Zn(3CO3)(OH)6. The increment of heating period is responsible to the amount of the achieved product.

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