Zinc Recovery from Electric Arc Furnace Dust Using Carbon and Ferrosilicon

S. Mohsen Moosavi Nezhad[1] Ahad Zabett[2]

1- Introduction

Electric arc furnace dust (EAFD) is annually generated about 6 million tons worldwide. The dust has classified as hazardous materials in US Environmental Protection Agency because of its toxic constituents. On the other hand, EAFD contains considerable amounts of zinc and iron which makes it worth of recovery treatments.

There are two main processes to recover zinc from EAF dust including pyro-metallurgical and hydrometallurgical methods. Nowadays more than 95 wt% zinc recovered from EAFD is treated by pyro-metallurgical processes. In the pyro-metallurgical method, the dust is reduced by a reduction agent at high temperatures (higher than 1100°C) and finally zinc or zinc oxide is obtained as a result of reduction of zinc compounds.

Lowering the temperature and time of a zinc recovery process causes significant decrease in production cost. In some new researches, to increase kinetic of reduction process, ferrosilicon was added to carbon in the reduction of metal concentrates. Ferrosilicon provides necessary condition to form liquid slag at lower temperatures and improves kinetic of zinc reduction reactions. We showed, in our previous study [1], that in the presence of ferrosilicon, liquid slag can be thermodynamically produced in the temperature range of 950-1050°C. In this study, effect of ferrosilicon addition on kinetic of zinc recovery process from the dust was experimentally investigated in details.

2-Exprimental

EAFD of Esfarayen Industrial Complex was used. Graphite and ferrosilicon (75 wt% Si) were used as reductants in the recovery treatments.

Before the main recovery step, a pretreatment step was performed at lower temperature to remove volatiles and increase the purity of final zinc product. In this step, 100g of the dust was heated at 875°C for 4h. After cooling, solid residue (called as pretreated dust) was used as initial material for recovery treatment. The chemical composition of the initial dust and pretreated dust are reported in Table 1.

In the main recovery step, a cylindrical steel reaction chamber was used. The cylindrical chamber was designed to be an isolated system with two separate parts. One for evaporation of zinc (hot compartment) and one for transportation and condensation of zinc vapor (cold compartment). In each experiment 2g of pretreated dust with predetermined amounts of carbon and ferrosilicon was mixed and replaced in the hot compartment of the reaction chamber. Then two compartments were linked together. The furnace was preheated well before each experiment started. The reaction chamber was inserted to the furnace from an opening hole on the furnace door.

Table 1 Chemical composition of the Initial and pretreated dusts

Initial	elem	Fe	O	Zn	Ca	Pb	K	Si
	Wt%	30.0	24.70	19.02	4.50	0.99	2.80	0.16
	elem	Na	Mg	Al	Cr	Cl	C	Cd
	Wt%	3.38	4.99	0.53	0.34	6.45	1.2	0.04
Pretreated	elem	Fe	O	Zn	Ca	Pb	K	Si
	Wt%	34	29.5	21.45	5.00	0.06	0.05	0.16
	elem	Na	Mg	Al	Cr	Cl	C	Cd
	Wt%	0.40	5.55	0.59	0.38	0.60	2.22	0.01

When temperature of hot compartment reaches to the predetermined temperature, is considered as time zero of experiments. After a certain time period, the apparatus was withdrawn from the furnace and cooled down in the air. Samples for chemical analysis were taken after mixing the residue for homogeneity in composition.

Computer calculations was performed using FactSage 6.1 software program and EQUILIB module of this software.

3-Results and Discussion

According to Table 1, after pretreatment, removal degrees of 98%, 94% and 88% were achieved for K, Pb and Na, respectively. The amount of zinc loss was about one weight percent.

Zinc recovery of samples with and without silicon are plotted against duration of experiments in the range of 950-1050 °C in Fig. 1. Base of thermodynamic calculations, both two types show same zinc recovery values. As can be seen, higher zinc recovery achieves in the presence of silicon at all time and temperatures. For instance, after 30 minutes heating at 1000 °C the samples with and without silicon give zinc recoveries of 64% and 34%, respectively. In the absence of silicon, the slope of zinc recovery curve is approximately constant up to 60 minutes heating. However, for samples containing silicon this slope was significantly decreased after 20-30 minutes heating. Higher zinc recovery rate at the first 30 minutes corresponds to formation of liquid slag phase which provides better kinetic condition for zinc recovery reactions.

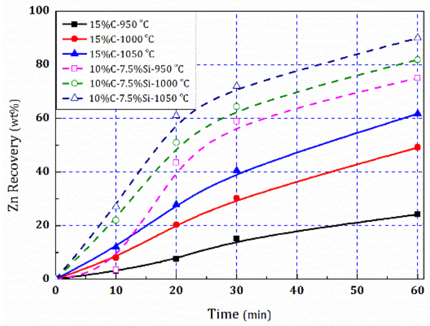

Fig. 1 Effect of temperature and time on zinc recovery of pretreated dust

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[1]Assistant Professor, University of Gonabad.

[2] Corresponded Author: Associate Professor, Department of Materials Science and Engineering, Ferdowsi University, Mashhad, Iran.
Email: ahad@um.ac.ir

Fig. 2 shows metallography image of solid residue for the sample containing silicon heated for 1 h at 1000 °C. Bright and dark fields are respectively correspond to metallic phase and cavities enclosed in slag. The cavities can be produced due to removal of the dust particles enclosed in the slag during polishing of the sample. Also, some of the cavities are bubble gas that arrested in the slag during its solidification. Slag consists the main portion of metallic phase. Metallic iron produced due to the reduction of oxide particles, consists other part of the metallic phase.

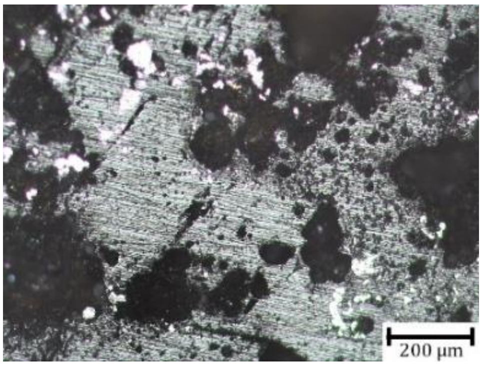

Fig. 2 Metallography image of the solidified slag after 1 hour heating at 1000 °C

Silicothermic reduction reactions of iron oxides are exothermic and can increase local temperature of samples containing ferrosilicon. Therefore, internal temperatures of these samples were recorded. Fig. 3 shows temperature changes of a points during heating of one of the samples containing ferrosilicon. A significant increase in the temperature can be seen when it reaches 950 °C and temperature rose up to approximately 1090 °C within a few minutes. Temperature fluctuates at temperatures higher than 1060 °C for a few minutes and then decreases to furnace temperature and fixes at this temperature (1000 °C). Heat production and local increase in the temperature as a result of silicothermic reactions has predicted by T. Hu et al [2].

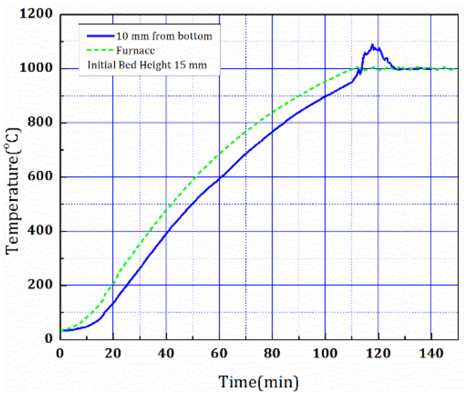

Fig. 3 Time-Temperature curve of a point with 10 mm height from the bottom of the sample containing ferrosilicon during heating

According to EDS results, the slag phase is mainly consists of silicon, iron and calcium oxides. Absence of zinc oxide is due to the reduction and vaporization of zinc. This vaporization increases melting point of the slag and leads to its solidification. Formation of liquid slags with melting points as low as 1100 °C in the FeO-ZnO-SiO_2-CaO system was reported by Jac et al [3]. Considering the local temperatures as high as 1090 °C, formation of liquid slag phase is possible.

The mechanism of dust reduction in the presence of carbon and silicon can be explained as bellow. Heating the samples up to 950 °C leads to starting silicothermic reactions. These exothermic reactions increases local temperature of the samples and causes formation of liquid slag. Therefore, carbon particles will be surrounded by the liquid phase and the reduction of ZnO of the slag by carbon particles will happen in the slag/carbon interface. Moreover, partial dissolution of carbon in slag can occur at the interface of carbon-slag and causes homogenous reaction of carbon with zinc oxide in the liquid phase. This causes formation of gas bubble containing CO, CO_2 and Zn at the interface. Metallic iron can also be nucleated at the slag-carbon or slag-bubble interface, as one of reduction products. In the final stages of the reduction process, solidification of liquid slag takes place as a result of decrease in the content of zinc oxide in the slag and diminishing of exothermic reactions. Presence of metallic iron and iron-carbon alloy particles in the solidified slag is confirmed by EDS graphs. These phases can be seen in Fig. 4.

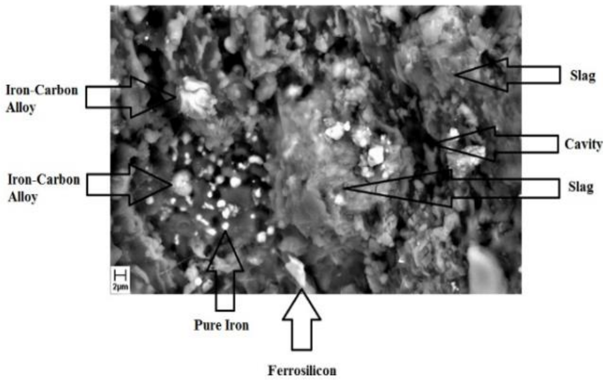

Fig. 4 SEM image of the solidified slag in the back-scattered mode

4- Conclusions

Reduction of zinc from electric arc furnace dust using carbon and ferrosilicon was investigated in the temperature range of 950-1050 °C. It was found that substitution of carbon by silicon leads to the formation of liquid slag and improves the rate of reduction up to three times. It was concluded that the kinetics of the process has improved in the presence of liquid slag. Occurring reduction reactions homogenously in the liquid slag by partial dissolution of carbon and providing extensive interfacial area between the metal oxides and reductants are the reasons for an improvement in kinetic.