Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 25(2015) 2753−2762
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Optimization of selective leaching of Zn from electric arc furnace steelmaking dust using response surface methodology

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Received 2 October 2014; accepted 20 January 2015

Abstract: The aim of this work is to investigate and optimize the effects of the leaching parameters on the selective leaching of zinc from electric arc furnace steelmaking dust (EAFD). The response surface method was applied on the basis of a three-level Box–Behnken experimental design method for optimization of selective leaching parameters of zinc from EAFD. The leaching recoveries of zinc (Y_{Zn}) and iron (Y_{Fe}) were taken as the response variables, where the concentration of sulphuric acid (X_1, mol/L), leaching temperature (X_2, °C), leaching time (X_3, min), and liquid/solid ratio (X_4, mL/g) were considered as the independent variables (factors). The mathematical model was proposed. Statistical ANOVA analysis and confirmation tests were applied. A maximum of 79.09% of zinc was recovered while the minimum iron recovery was 4.08% under the optimum conditions of leaching time 56.42 min, H_2SO_4 concentration 2.35 mol/L, leaching temperature 25 °C and liquid/solid ratios. By using ANOVA, the most influential factors on leaching of zinc and iron were determined as H_2SO_4 concentration and leaching temperature, respectively. The proposed model equations using response surface methodology show good agreement with the experimental data, with correlation coefficients (R^2) of 0.98 for zinc recovery and 0.97 for iron recovery.

Key words: EAFD; zinc; iron; selective leaching; optimization; Box–Behnken design

1 Introduction

Electric arc furnace dust (EAFD) is one of the most critical wastes encountered in steelmaking industries. During the meltdown of scrap, volatile components are fumed off and are collected with particulate matter in the off-gas cleaning system [1,2]. EAFD contains mainly Zn, Fe, Pb and a considerable amount of harmful elements, such as Cd, As, Cr and F. The contents of the main elements in EAF dusts may vary between: 30% of Zn, 0.3%–6% of Pb, 0.01%–0.2% of Cd, 20%–35% of Fe, 0.2%–0.7% of Cr, 1%–10% of Ca, etc [3–6]. $ZnFe_2O_4$, Fe_3O_4, $MgFe_2O_4$, $FeCr_2O_4$, $Ca_{0.15}Fe_{2.85}O_4$, MgO, Mn_3O_4, SiO_2 and ZnO phases were detected in EAFD [7].

The world generation of EAFD is estimated to be 5−7 million tons per year [7]. Zinc in the EAFD is the most valuable component due to its relatively large amount [8]. Therefore, the selective recovery of zinc from EAFD with a high percentage is an attractive option considering its low production cost.

To date, many processes have been or are being investigated worldwide to recover zinc from the EAFD [1,2,5,9−12]. For this purpose, metallurgical processing can be performed by either pyrometallurgical or hydrometallurgical routes. In pyrometallurgical processes, such as carbothermic reduction, the low-grade zinc in the residue leads to high energy consumption [6], because these processes require high heating of gangue materials. Yet, only 70% of total Zn recovery can be obtained. Given these challenges, a variety of hydrometallurgical processes such as high pressure acid leaching [5], two-stage acid leaching [13], microwave caustic leaching [10], and the use of solutions with various acids [5,9,11,12,14] or highly concentrated alkaline solution have been studied [8,13]. Also, hybridization of pyrometallurgical or hydrometallurgical routes were applied to recovering zinc from EAFD [13]. BARRERA [15] treated electric arc furnace dust (EAFD) for the recovery of zinc following pyro-hydrometallurgical method. Although there are so many studies on the leaching of EAFD, the process optimization by using RSM of the selective sulphuric acid leaching of zinc from EAFD has not been reported in literature. Hence, the present work intends to assess the effects of variables to identify the optimum

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DOI: 10.1016/S1003-6326(15)63900-0

conditions using a Box–Behnken design.

To produce electrolytic metallic zinc, an acid leaching step is required in order to lixiviate the highest possible zinc quantity. Sulphuric acid leaching is more suitable than HCl leaching because of the absence of chlorine/chloride and lower lead concentrations. The zinc recovery that can be achieved with this kind of acid liquors lies between 75% and 90% [14,16]. Once the leaching is finished, the liquor obtained is sent to the purifying stages. The first purifying stage is usually oxidation in order to remove the iron as ferric hydroxide sulphate, $Fe(OH)SO_4$. Different oxidation agents may be employed, such as hydrogen peroxide, air, manganese dioxide, or a combination of them. After the oxidation, a cementation step is usually carried out to reduce cadmium, lead and copper concentrations. In this step, zinc dust is usually employed as cementation agent [14,16]. The present study attempts to identify extraction conditions that could possibly maximize the zinc recovery but minimize the iron recovery using sulphuric acid from EAFD by optimizing the process conditions, by designing the experiments using response surface methodology (RSM). Thus, the first purifying stage of pregnant zinc leach solution could be achieved easily and economically. Although, RSM has been a common practice in searching optimal conditions in a variety of research topics, there were no reports, thus far, describing the use of the statistical experimental design approach to improve the selective sulphuric acid leaching of zinc from EAFD.

The general practice for determining the important process parameters for leaching is conducted by varying one parameter and keeping the others at a constant level. This is the one-variable-at-a-time technique. The major disadvantage of this technique is that it does not include interactive effects among the variables and, eventually, it does not depict the complete effects of various parameters on the process. In order to overcome this problem, optimization studies can be carried out using the RSM. The basic theoretical and fundamental aspects of RSM have been described in the related literature [17,18]. RSM is the most popular technique used to find the optimal conditions by using quadratic polynomial model and is applied as a consequence of a screening or diagnostic experiment [18,19]. RSM reduces the number of experimental trials needed to evaluate multiple parameters and their interactions; therefore, it is less laborious and time-consuming than other approaches. So, the experimental and analytical methods using RSM are more advanced than one-variable-one-time method. RSM has been applied to modelling and optimization in leaching processing [19–22].

Although there are so many studies on the leaching of EAFD, the process optimization using RSM for the selective sulphuric acid leaching of zinc from EAFD has not been reported in literature. Hence, the present work intends to assess the effects of variables such as sulphuric acid concentration, leaching time and temperature, and liquid/solid ratio to identify the optimum conditions using a Box–Behnken design. Moreover, the interactions among various factors may not be ignored, hence the chance of approaching a true optimum is very likely. The characteristics of sample are assessed using the analytical instruments such as X-ray diffraction (XRD) and atomic absorption spectrometry (AAS).

2 Experimental

2.1 Materials and apparatus

The chemical composition of EAFD was determined by AAS (GBC Sigma model AAS) and gravimetric & volumetric analysis methods. These results are presented in Table 1. In order to determine the compounds (phases) in EAFD, XRD analysis was performed, and the result is shown in Fig. 1. According to the XRD pattern, ZnO, $(MgO_{0.26}Mn_{0.397}Fe_{0.571}Zn_{0.006})(Mg_{0.449}Ti_{0.002}Mn_{0.0049}Fe_{1.497})O_4$ and $(Zn_{0.06}Fe_{0.04})(Fe_{0.98}Zn_{1.02})O_4$ phases were present in the EAFD. The original shape of EAFD sample was agglomerated sphere and the size was 1−3 mm in diameter. But when the sample was added to leaching solution, it would separate and turn to very fine powder particles in the leaching solution. Therefore, it was not ground for fineness.

Table 1 Chemical composition of EAFD (mass fraction, %)

Zn	Fe	Pb	Cd	SiO_2	CaO	Al_2O_3
26.95	27.39	3.75	0.12	3.53	3.49	1.47

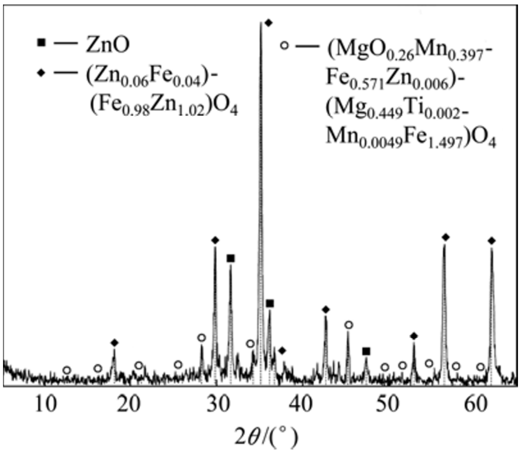

Fig. 1 XRD pattern of EAFD

2.2 Experimental methods

The leaching solution was prepared by mixing