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BEHAVIOR OF ZINC, CALCIUM AND IRON IN THE TWO-STAGE LEACHING PROCESS OF THE EAF DUST

Vanja Trifunović[1a], Snežana Milić[2a], Ljiljana Avramović[1b], Dragana Božić[1c], Zoran Avramović[1d]

[1] Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia
[2] Technical Faculty Bor, University of Belgrade, V.J. 12, 19210 Bor, Serbia
[1a] vanja.trifunovic@irmbor.co.rs, 0000-0003-4839-8751
[2a] smilic@tfbor.bg.ac.rs, 0000-0002-5000-9156
[1b] ljiljana.avramovic@irmbor.co.rs, 0000-0002-3747-1530
[1c] dragana.bozic@irmbor.co.rs, 0000-0003-1055-8449
[1d] zoran.avramovic@irmbor.co.rs, 0009-0006-7585-976X

Abstract

The treatment of the EAF dust was carried out by applying the leaching process in two technological stages in order to selectively separate certain components from the EAF dust. In the first stage, a pre-treatment was performed to selectively remove water-soluble components from the original EAF dust sample, while in the second stage, zinc was selectively separated from the resulting solid residue by acid leaching. In the second stage of the leaching process, the influence of the acid leaching process time on the zinc, calcium and iron leaching rates were investigated. Selective zinc recovery from the EAF dust was achieved with the following optimal parameters of the acid leaching process: leaching reagent 1.0 M solution of H_2SO_4, ambient temperature, S:L ratio =1:4, time 10 min and stirring speed 500 rpm. The zinc leaching rate in the second leaching stage was 60.74%, while the Ca and Fe leaching rates were significantly lower and amounted to 12.18% and <0.01%, respectively.

***Keywords**: EAF dust, two-stage leaching, selectivity*

1. INTRODUCTION

In steel production, as in other branches of industry, waste is generated. The production of steel in electric arc furnaces, for which scrap iron is used as a batch, generates electric arc furnace dust (EAF dust) as an intermediate product of the process. During the production of 1 t of crude steel, 10-20 kg of EAF dust containing Zn, Fe, Pb, Cl, Ca, Na, K, Cr, Mg, Mn, Ni, Si, Cd and others is obtain [1-4]. If the EAF dust is disposed of in an inadequate way, due to the action of atmospheres, the heavy metals contained in it may self-leach and have a negative impact on the environment. For this reason, EAF dust has been characterized worldwide as a hazardous industrial solid waste [5-7]. Despite the harmful characteristics of the EAF dust, there are several benefits of its further treatment. The first is environmental protection, with the aim of reducing hazardous waste or its transformation into non-hazardous waste, as well as its safe disposal at a landfill. Another benefit is the valorization of valuable metals present in the EAF dust, primarily zinc, and the achievement of [1,2,5]. Treatment of the EAF dust can be carried out in three ways, namely by: hydrometallurgical, pyrometallurgical or combined process which represents a combination of elements of both previous processes [2-5,7].

The application of the pyrometallurgical process for the EAF dust treatment leads to the consumption of a large amount of energy, because the processes take place at high temperatures and it is not possible to apply it to raw materials with a zinc content lower than 15%. The product obtained by applying this process - ZnO, has little commercial value [3,8]. On the other hand, the hydrometallurgical process takes place at temperatures lower than 100°C, and is applied to raw materials with a low zinc content, using low-cost and easily available chemicals, and the obtained product is of high quality. The hydrometallurgical process includes three technological stages:

leaching, purification of the pregnant leaching solution and recovery of metals or compounds from the purified pregnant leaching solution [2-4,7].

In this paper, the chemical and mineralogical characterization of the original EAF dust sample was carried out, and then the two-stage leaching process of the EAF dust was investigated, which aimed to selectively separate zinc into the pregnant leaching solution, with minimal extraction of other components, in the paper, iron and calcium.

2. EXPERIMENTAL

2.1 Chemical and mineralogical characterization of the original EAF dust sample

The chemical composition of the original EAF dust sample was performed using an Atomic Absorption Spectrophotometer, brand Perkin Elmer PinAAcle 900F (USA), and an Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES), brand Spectro Ciros CCD/Vision (Germany). X-Ray diffractometer (XRD), model RigakuMiniFlex 600 (Japan) was used for mineralogical characterization of the original EAF dust sample.

2.2 Two-stage leaching of the EAF dust

The aim of the two-stage leaching process of the EAF dust is to leach zinc, with minimal leaching of other components that will contaminate the zinc solution and further make difficult its recovery as a final product. The leaching process investigated in this paper was carried out in a glass reactor with a volume of 2L, in two stages. The first stage was pretreatment of the EAF dust - water leaching, and the second stage - acid leaching of the solid residue obtained after the pretreatment. In the pretreatment stage of the EAF dust, the original EAF dust sample was leached with distilled water, in order to selectively separate water-soluble components from the EAF dust. The pretreatment was carried out at ambient temperature, with a ratio of solid to liquid phase of 1:10, in time of 30 minutes, at a stirring speed of 500 rpm, as defined in the investigation of the authors Trifunović et al. [1]. The second stage of the EAF dust leaching process was the acid leaching of the solid residue obtained after the applied pretreatment. In this stage, the influence of the leaching time (5, 10, 15, 20, 30 and 60 minutes) on the zinc, calcium and iron leaching rates were investigated. The experimental investigations were carried out at ambient temperature, with a ratio of solid to liquid phase 1:4, stirring speed 500 rpm, and sulfuric acid with an initial concentration of 1.0 M was used as the leaching reagent. The applied acid leaching process parameters are similar to the process parameters in the investigations of other authors [4,5]. The goal of this leaching stage was the selective separation of zinc, with a significant leaching rate, and with as little leaching rate of iron and calcium, present in the EAF dust.

3. RESULTS AND DISCUSSION

The chemical composition of the original EAF dust sample indicated the content of the following elements: Zn - 36.40%; Fe - 21.58%; Ca - 3.02%; Pb - 1.86%; Na - 1.18% and others, with a significantly smaller share. The mineralogical phases of the original EAF dust sample, determined by XRD analysis, are presented in Figure 1. Four phases were identified, namely: franklinite ($ZnFe_2O_4$), magnetite (Fe_3O_4), zincite (ZnO) and simonkolleite ($Zn_5(OH)_8Cl_2 \cdot H_2O$). Franklinite, magnetite and zincite occur as the main phases, while simonkolleite was the least abundant phase of the EAF dust. The obtained results of the XRD analysis for the identified mineralogical phases of the analyzed EAF dust are in agreement with the literature [1-3,5].

With the first stage of the two-stage leaching process the selective separation of water-soluble components from the EAF dust, that is, Cl, Na and K. Zinc and iron after the pretreatment remain in the solid residue completely, while Ca in it was about 90% of the initial amount in the original EAF dust sample. The amount of Ca in the solid residue, in the investigated EAF dust, is most likely in the form of compounds that are not soluble in water, such as $Ca(OH)_2$ and $CaSO_4$. The

same conclusion is reached by Montenegro et al. [4] and Al-Harahshes et al. [8] in their investigations, in which they applied a pretreatment, leaching the EAF dust with water.

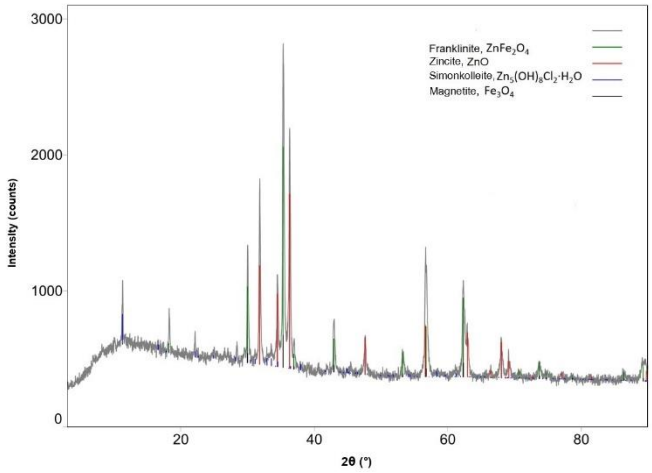

Figure 1. Diffractogram of the original EAF dust sample

Chemical analysis of the solid residue obtained from the pretreatment of the EAF dust determined the following contents: Zn - 39.4%; Fe - 23.37%; Ca - 2.70%; Pb - 2.02%; Na - 0.27% and very low concentrations of other elements.

The application of the pretreatment leads to a number of advantages for the next stage of the leaching process. Contamination of the pregnant leaching solution with water-soluble components is avoided, there is a mass reduction of about 6% compared to the mass of the initial sample, and the consumption of sulfuric acid in the next stage of acid leaching is also reduced. Figure 2 presents the zinc, calcium and iron leaching rates depending on the time of the sulfuric acid leaching process.

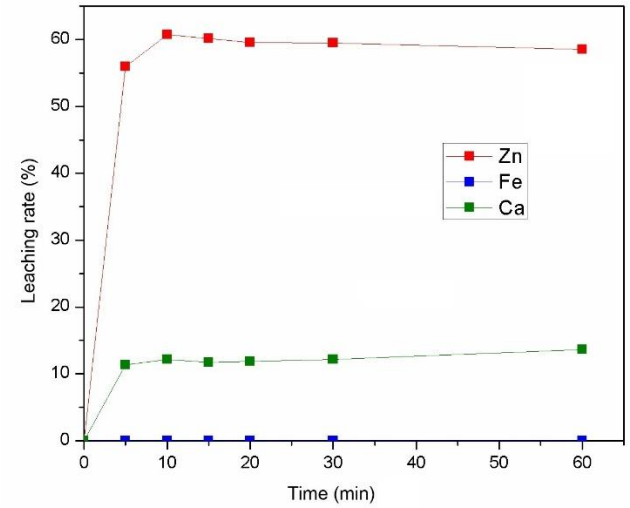

Figure 2. Zinc, calcium and iron leaching rates depending on the time of the acid leaching process

Based on the obtained results, it can be concluded that the highest level of zinc leaching was achieved after 10 minutes of the acid leaching process and is 60.74%. Further, with time, the zinc leaching rate decreases slightly. A calcium leaching rate of 12.18% is also achieved after 10 minutes of the leaching process, it decreases to 11.70% at 15 minutes, and with further time, at 60 minutes it is 13.60%. The iron leaching rate, at all investigated times of the acid leaching process, was negligible, amounting to less than 0.01%. The chemical and mineralogical composition of the EAF dust affects the leaching rates of elements, as do the leaching process conditions. With the application of elevated temperatures and higher acid concentrations, it is likely that the Fe leaching rate would increase. Given that in this paper there are no significant changes in the leaching rates

of zinc, calcium and iron after 10 min, this time can be considered the optimal parameter of the acid leaching process, which achieves the selective separation of zinc from the EAF dust, with minimal leaching of other components.

The reactions of zinc, iron and calcium compounds from the EAF dust with sulfuric acid can be described by the following equations [5]:

$$ZnO + H_2SO_4 = ZnSO_4 + H_2O \quad (1)$$
$$ZnFe_2O_4 + 4H_2SO_4 = ZnSO_4 + Fe_2(SO_4)_3 + 4H_2O \quad (2)$$
$$Fe_3O_4 + 3H_2SO_4 = Fe_2(SO_4)_3 + 3H_2O \quad (3)$$
$$Ca(OH)_2 + H_2SO_4 = CaSO_4 + H_2O \quad (4)$$
$$CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2 \quad (5)$$

In a study by Montenegro et al. [4] after the pretreatment (water leaching), the solid residue was leached with a 1.0 M solution of H_2SO_4, at a ratio of S:L=20%, for 20 min, at a stirring speed of 500 rpm. The zinc leaching rate was 74%, while the iron leaching rate in the investigation of these authors was 8%. Kukurugya et al. [5] in their investigation of the acid leaching process monitored the leaching rates of Zn, Fe and Ca at concentrations of H_2SO_4 from 0.05 to 1.0 M, at the ratio S:L=50, at temperatures from 20 to 95°C, for times: 1, 5, 10, 15, 30, 60 and 90 min. The maximum zinc leaching rate of 87% was achieved with a concentration of H_2SO_4 of 1.0 M, at a temperature of 80°C and for a time of 60 min.

4. CONCLUSION

The results of the experimental investigations in this paper showed that the selective separation of Zn from the investigated EAF dust can be achieved by applying the two-stage leaching process. In the first stage, the pretreatment stage, the removal of water-soluble components from the original EAF dust sample is achieved, while in the second stage, by acid leaching of the solid residue obtained after the pretreatment, with appropriate process parameters, Zn is selectively separated, in the amount of 60.74%, with low levels of Ca and Fe leaching. The Fe leaching rate is determined by the chemical and mineralogical composition of the EAF dust, as well as the process parameters. It is likely that a higher leaching rates would be achieved by applying more rigorous leaching conditions, i.e. higher temperatures and acid concentrations. In the second stage of acid leaching, the optimal process parameters in this paper were: 1.0 M solution of H_2SO_4 as leaching agent, ambient temperature, S:L ratio =1:4, time 10 min and stirring speed 500 rpm.

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REFERENCES

[1] V. Trifunović, S. Milić, Lj. Avramović, M. Bugarin, S. Đorđievski, M.M. Antonijević, M.B. Radovanović., Metals, 14 (2024) 426.
[2] V. Trifunović, S. Milić, Lj. Avramović, R. Jonović, V. Gardić, S. Đorđievski, S. Dimitrijević., Hem. Ind., 76 (4) (2022) 237-249.
[3] J. Gamutan, S. Koide, Y. Sasaki, T. Nagasaka., J. Environ. Chem. Eng., 12 (2024) 111789.
[4] V. Montenegro, S. Agatzini-Leonardou, P. Oustadakis, P. Tsakiridis., Waste Biomass Valorization., 7 (6) (2016) 1531–1548.
[5] F. Kukurugya, T. Vindt, T. Havlík., Hydrometallurgy, 154 (2015) 20–32.
[6] P.K. Hazaveh, S. Karimi, F. Rashchi, S. Sheibani., Ecotoxicol. Environ. Saf., 202 (2020) 110893.
[7] J. Wang, Y. Zhang, K. Cui, T. Fu, J. Gao, S. Hussain, T.S. AlGarni., J. Cleaner Prod., 298 (2021) 126788.
[8] M. Al-Harahsheh, Y. Orabi, S. Al-Asheh., J. Environ. Chem. Eng., 9 (2021) 105410.