29th International Conference Ecological Truth & Environmental Research
21 - 24 June 2022, Hotel Sunce, Sokobanja, Serbia
www.eco.tfbor.bg.ac.rs

ELECTRIC ARC FURNACE DUST – HAZARDOUS INDUSTRIAL WASTE WHOSE TREATMENT IS UNAVOIDABLE

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Abstract

Electric arc furnace dust (EAF dust), which is formed as a by-product of the steel production process from secondary raw materials, contains significant amounts of Zn, Fe, Pb, Cd, Ca, K, Cr, Mn, Si, Mg, Na, Ni, Cu, F, Cl, etc. Due to the content of heavy metals in the EAF dust, which in its inadequate disposal and the impact of atmospheric conditions can lead to a negative impact on the environment, it is characterized in the world as hazardous industrial solid waste. For environmental protection, it is necessary to do a treatment of the EAF dust so that it can be safely disposed of in a landfill without negative effects on the environment and human health. In addition to environmental benefits, the EAF dust treatments can also have economic benefits.

Keywords: EAF dust, hazardous waste, environmental protection

INTRODUCTION

World production of crude steel takes place in two ways: processing of primary raw materials, primarily iron oxide ore, melting in the Basic Oxygen Furnace (BOF) and processing of iron-based secondary raw materials by melting in an Electric Arc Furnace (EAF) [1–4].

Using secondary raw materials, i.e. scrap iron, as a raw material for steel production, and electricity as an energy source, steel production in electric arc furnaces has become more prominent than any other steel production process in the world [5–11]. The main sources of secondary raw materials for steel production are construction material waste, old cars, appliances and household waste, which means that waste can contain a large number of metals, plastics and rubber, glass, paint, oil, and even salt [2,5–8,12]. Figure 1 shows an example of scrap iron used as a batch for an electric arc furnace [13].

During the melting process of scrap iron in the electric arc furnace at a temperature of 1600ºC, a by-product of the process-dust from the electric arc furnace is forming. Emission of the electric arc furnace dust (EAF dust) is proportional to the steel production so that with the increasing steel production there is an increase in the amount of the EAF dust: for each ton of produced crude steel about 10–20 kg of the electric arc furnace dust is also produced. About 5–7 million tonnes of dust are generated annually in the world, of which 0.5–0.9 million tonnes of dust come from steel plants in Europe [2,4–6,8,10,11,14,15].

Figure 1 *Scrap iron used as a batch in the steel production process from secondary raw materials [13]*

Formation of the EAF dust occurs since volatile elements, such as Zn, Pb and Cd in the batch of the furnace mostly evaporate in the early stages of the operation, and eventually, all of them go into the gas phase. Other elements, such as Fe, Cr, Ni and Mn, are generated from gaseous products during the refining period, mainly due to oxygen injection. Volatile components are rapidly converted into the corresponding oxides in contact with air after the combustion and cooling of the exhaust gases [1,2,5,7]. Oxides in the slag mixed with metal vapors and generated dust are extracted from the furnace by hot gas flow, to a gas purification system where gases are cooled down, and finally, the EAF dust is formed which can be collected in a gravity collector, electrostatic dust collector, or filter bags [1,5,14].

EAF DUST CHARACTERIZATION

Electric arc furnace dust occurs in the form of very fine reddish-brown or dark brown particles, which can spread in the air [5,7]. Due to the difference in the procedures for obtaining steel in an electric arc furnace and the methods of collecting the EAF dust, the physical characteristics of EAF dust will vary within the appropriate range. For example, depending on the way the EAF dust is collected, the size of its particles will vary. When the EAF dust is collected with a gravity collector, 85% of dust particles are <10 μm, by collecting in filter bags, 90% of particles are <50 μm, and in an electrostatic collector, more than 90% of dust particles are <100 μm in size [5].

To a large extent, the composition of the EAF dust depends on the operating conditions of the electric arc furnace, the characteristics of the scrap iron batch, the working period, the specifications of the produced steel, and is also specific to each plant [1,2,6,8,14]. The composition of EAF dust can be variable and can change from day to day in the same steel plant [1]. EAF dust is the final result of a series of physical and chemical phenomena through which substances that create EAF dust pass and they define its physical aspect, chemical and mineral composition. Basically, EAF dust should consist of iron oxides, however, due to the presence of different types of scrap iron, which contains several different elements, its composition becomes complex [1,11]. It can be seen from Table 1 that the chemical composition of EAF dust from different sources can vary significantly.

Table 1 *Comparative chemical composition of the EAF dust from different sources*

Elements (%)													Ref.
Zn	Fe	Pb	Ca	Cd	Na	K	Cl^-	Mn	Si	Cr	Cu	Al	
22.73	14.40	4.22	13.32	0.09	1.25	1.61	4.75	1.00	1.45	-	-	-	[3]
29.10	24.00	3.64	3.16	-	-	1.76	1.56	4.11	1.57	-	0.25	0.52	[12]
17.80	4.20	2.34	0.80	-	-	-	1.60	0.62	8.14	-	-	0.73	[17]
33.00	26.50	2.17	0.90	-	-	-	-	2.30	-	0.20	0.20	-	[19]
24.24	34.38	1.76	2.27	-	-	-	4.72	-	-	-	-	-	[14]
7.79	37.29	1.16	5.33	-	2.78	3.11	2.63	1.18	2.21	0.15	-	-	[18]

As for the mineral composition, because the EAF dust is formed in oxidative conditions, most metals are present in the form of oxides. Zinc occurs in the form of ZnO and $ZnFe_2O_4$, while iron mainly occurs in the oxide form as Fe_3O_4 and Fe_2O_3 [1,2,6,8,11]. Calcium is present in the form of CaO, $CaCO_3$, calcium silicate, and calcium aluminosilicate. Lead, copper, chromium, and nickel can occur in the form of oxides, chlorides, sulfides, or sulfates. In recent years, there has been an increase in chlorine levels in the EAF dust due to an increase in impurities containing chlorine in scrap iron (most commonly rubber, paints, polymers, etc.), and it occurs in the form of alkali metal chlorides [1,2].

EFFECT OF EAF DUST ON THE ENVIRONMENT

The presence of metals such as Pb, Zn and Cd in the EAF dust can pose a threat to the environment and human health due to the mobility of these toxic elements, and for this reason, EAF dust is considered hazardous industrial solid waste in many countries [1,4–6,8]. According to the Environmental Protection Agency (EPA) in the United States it is characterized as hazardous solid industrial waste K061 [4], according to the Brazilian standard ABNT 10004: 2004, EAF dust is listed as hazardous waste from a specific source K061 [5,20], in the catalog of the European Union Waste [21] it is included in the list of hazardous substances with the code 10 02 13, and according to the European catalog of waste [22] it is classified as a hazardous waste of category 10 02 07 [6]. It is also considered an air pollutant because the gas purification system captures only 70% of the EAF dust, while the rest goes into the atmosphere. Therefore, EAF dust is a solid hazardous waste that has the potential for long-term environmental pollution [23].

The pollution potential of this type of waste lies in the possibility of self-leaching elements such as Zn, Cu, Cr, Ni, Pb, Cd, F, and Cl. Factors that play a significant role in increasing the solubility of heavy metals from the EAF dust in the environment are pH, redox potential, and temperature. Controlling these factors, the risk of environmental contamination with heavy metals from the EAF dust can be reduced [23]. Disposal of this hazardous waste has become a serious problem in recent years since increasing steel production increases the amount of hazardous waste that needs to be adequately treated, in prescribed landfills, to prevent its negative impact on the environment and human health. It is understood that when disposing of the EAF dust in hazardous waste landfills, the EAF dust must be protected from rain to prevent the formation of leachate that could contaminate the land and watercourses in the surrounding area [4,24]. Figure 2 shows the “mountain” of disposed EAF dust generated from steel production in Egypt [14]. As can be seen from the figure, this method of disposal is not adequate since hazardous waste is completely exposed to external atmospheric influences and it is very easy to contaminate the environment with heavy metals from the dust [4,15,24].

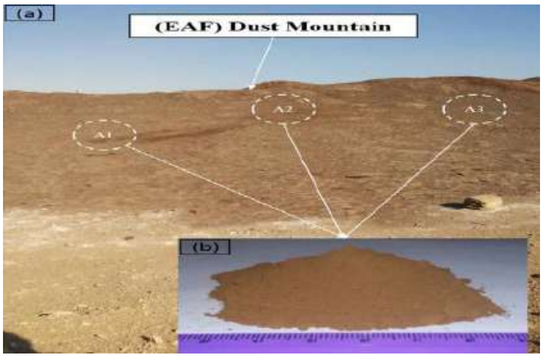

Figure 2 *a) "Mountain" of the EAF dust generated from steel production in Egypt; b) a representative sample of the EAF dust [25]*

EAF DUST TREATMENT TO ENVIRONMENTAL PROTECTION

For environmental protection and the protection of human health, it is necessary to do a treatment of this type of hazardous waste. Certain treatments of the EAF dust, in addition to reducing the amount of hazardous waste and/or its transformation into non-hazardous waste to protect the environment, would also make savings on the cost of its disposal. Also, in addition to environmental benefits, economic benefits could be achieved by extracting zinc for commercial quality products and using iron concentrates suitable as raw materials in steel or pig iron production [1,6,14].

Although very rich in iron, EAF dust cannot be recycled directly into the steel production process, because it contains large amounts of Zn (from 2–40% [3,8,12,14,17–19]), which negatively affects the electric arc furnace and thus endangers the economy of the furnace. Although chrome and lead are not problematic for the steel production process itself, they are toxic to humans and their content is regulated by the European Commission. Consequently, metal separation has become a desirable option, as the EAF dust is a quality secondary raw material for zinc production – EAF dust contains approximately 7% of world zinc production that would otherwise be thrown in landfills. With the constant increase in demand for zinc and with limited possibilities of its substitution in materials and the depletion of reserves from its primary sources, the need for secondary sources of zinc is growing. Therefore, the EAF dust treatment process must be able to remove Zn from the dust, while the remaining valuable metals are compatible with iron and steel so that the iron-containing material can be recovered and recycled in the steel production process, or to obtain a solid residue that can be safely disposed of as non-hazardous waste [8]. Efficient extraction of zinc from secondary sources has several advantages such as: saving intact resources and fossil resources used to supply energy in primary mining processes, increased resource efficiency, reduced landfill disposal and loss of zinc or any metal returned to landfill, waste remediation, as well as reduction of environmental impact [23].

Given the potential environmental and economic benefits from the EAF dust, it is important to develop appropriate processes for its treatment. The chemical composition of the EAF dust, as well as its available amount, provides opportunities and conditions for deciding on the best sustainable method for its treatment. For the recycling of the EAF dust for zinc separation to be economically viable, the dust must contain Zn concentrations higher than 15% [20]. In general, there are two basic processes in the EAF dust treatment: the pyrometallurgical process and the hydrometallurgical process. Both processes have their advantages and disadvantages. Pyrometallurgical processes require high temperatures, expensive equipment, and large capacity plants, which leads to high energy consumption. For the treatment of the EAF dust by pyrometallurgical processes, the minimum zinc content in the dust must be >15% to ensure the economy of the process. By applying this process, a product ZnO of low commercial value is obtained, which requires additional hydrometallurgical treatment. Also, in this process other solid residues are formed and need additional treatment before disposal [2,5]. On the other hand, the hydrometallurgical process can be economical with a zinc content in dust lower than 15%. These processes have significantly lower capital and operating costs compared to pyrometallurgical ones, can be installed in situ, and commercial quality products can be obtained. However, large amounts of wastewaters are generated that require further treatment to be safely discharged to recipients. Solid residues of these processes may or may not be subsequently treated before disposal. Extraction of zinc from the EAF dust by the hydrometallurgical process is very complicated and consists of several related processes, such as leaching, purification of pregnant leaching solution, and separation of metals/compounds [3,5,6,8,14].

Other methods of recycling the EAF dust were also investigated, not to separate valuable metals and obtain non-hazardous waste, but for direct disposal of the dust by incorporating dust containing zinc in a concentration of less than 15% in existing products. Products in which EAF dust can be incorporated are blue shales [15] for use in the cement industry, bricks [4], kaolin clay used for 3D printing in the construction industry [10], ceramic tiles, etc. In addition to saving on the costs of disposing of the EAF dust, its incorporation into existing products leads to improved physical characteristics of these products [4,10,15].

CONCLUSION

Dust from the electric arc furnace generated in the steel production process from secondary raw materials contains significant amounts of Zn, Fe, and Pb, as well as variable amounts of Cd, Ca, Cr, Mn, Si, Mg, Na, F, Cl, etc. Due to the content of heavy metals in the EAF dust, which can contaminate the surrounding lands and watercourses due to its inadequate disposal, and the influence of atmospheric conditions, it is characterized in the world as hazardous industrial solid waste.

EAF dust treatment processes for the recovery of valuable metals can be pyrometallurgical and hydrometallurgical processes, depending on dust chemical composition and the amount available for processing. All processes have their advantages and disadvantages.

For environmental protection, it is necessary to do the treatment of the EAF dust so that it can be safely disposed of in a landfill without negative effects on the environment and human health. In addition to environmental benefits, the EAF dust treatment can also have economic benefits.

The impact of incorporated EAF dust on the environment has not been sufficiently investigated.

ACKNOWLEDGMENTS

The authors are grateful to the Ministry of Education, Science and Technological development of the Republic of Serbia for financial support (Grant No. 451-03-68/2022-14/200052 and Grant No. 451-03-68/2022-14/200131).

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