Investigation of Dust Chemical Compounds Emitted by Electric Arc Furnace (EAF) with a reuse perspective

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ABSTRACT

In the process of steel production by electric arc furnace (EAF), it is found that 10 to 20 kg of dust was emitted per every ton of produced steel. Concerning the pollution potential of emitted dust and its reuse ability, the present study was aimed to determine the chemical composition of the electric arc furnace dust with a reuse perspective.
This study was done in a steel factory equipped with EAF. Local exhaust ventilation system is installed on the furnace and equipped with cyclone and venturi scrubber. To analysis of dust compounds were gathered in a cyclone and those left the system, the samples were taken from the cyclone hopper and exhaust fan outlet. Finally, the samples were analyzed by X-ray diffraction (XRD).
According to the results, the trapped dust in the cyclone and scrubber were 226.86 and 44.81 kg/hr, respectively. The results obtained from XRD analysis also showed that about 50% of the dust was formed by Fe_2O_3. The quotient of other compounds such as CaO, MgO, SiO_2, and Zn was more than 30%.
Conclusion: the results of this study showed that EAF dust composed of a range of elements with different concentrations. Given the high weight of these compounds, reusing some of these elements can be having a positive impact on health and the economy.

Key words: Electric Arc Furnace Dust, X-ray Diffraction, Reuse Perspective

List of Abbreviations

EAF: Electric Arc Furnace
XRD: X-ray diffraction
ICP: Inductively Coupled Plasma

INTRODUCTION

There are various methods for producing steel all of which share a basic problem and that is the release of dust and fumes [1]. Among the various steel production technologies, the use of EAF is increasingly applied to create high temperatures and reduced steel. According to statistics provided by internationally accredited institutions, approximately 35% of the world steel production totalled 1220 Million tons in 2009, has been produced using an EAF technology [2]. The amount of steelmaking was about 11 Million tons in Iran in 2010 which mainly produced using an EAF [1].
In the steelmaking process using an EAF, for each ton of steel produced, 10 to 20 kg of dust is released [3-6]. The global dust production of the EAFs is estimated at around 3.7 million tons per year which annually increases up to 4% - 6% [4]. According to the technical standard NBR10004 of Brazilian Association, an EAF dust is classified as hazardous waste due to its cadmium and lead content which is higher than the NBR10005 limit. The National Environmental Protection Agency of Rio has made steel mills to control and collect dust from EAFs to prevent environmental pollution [4, 5]; the best and most effective method for controlling and collecting contaminants, is to control the source of pollution [7, 8].
In developed countries, the process of controlling and collecting dust in the EAFs is carried out considering the following two objectives: capital recovery and environmental pollution prevention [6, 9]. Accordingly, recognizing the compositions of dust particles is important. The chemical composition of dust in the EAFs is very variable and not only depends on the scrap used and the type of steel produced but also on working circumstances and processes. Since the scrap used for galvanizing steel is increasing, the chemical compositions of zinc and lead are also increasing in the dust. Besides the elements e.g. lead and Zinc, high contents of iron and fewer contents of

manganese, calcium, sodium, and potassium, as well as minor amounts of other elements such as cadmium, chromium, nickel, copper, magnesium, silicon and chlorine, are also found in these dust [10].

Machado *et al.* investigated the chemical composition of dust in the EAFs using XRD and inductively coupled plasma (ICP). The study results indicated that the chemical compositions of the dust consist of $ZnFe_2O_4$, 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, where the highest weight percent of elements is related to iron (48%) and manganese (12 %) [5].

Given the increasing growth of steelmaking in Iran and the importance of industrial pollutants released in terms of cost and ecosystem, it is required to pay more attention to the chemical composition of these pollutants, as well as pollutants' controlling and collecting systems. Therefore, the present study is performed to determine the chemical composition of the electric arc furnace dust with a reuse perspective.

MATERIALS AND METHODS

The current study is part of a larger study carried out at an alloy steel plant equipped by the EAFs system. In the main study, the local exhaust ventilation system was designed for the EAFs and then the concentration of dust was measured in different parts of the ventilation system and the efficiency of the collectors was calculated. The present study is performed to determine the chemical compositions of the exhaust dust of the EAFs and the weight of each of these chemical compositions as well. The schematic view of the local exhaust ventilation system is designed and some of the data are presented in Fig. 1.

C1: inlet dust concentration to the cyclones equals to 3710 mg/m^3, C2: inlet dust concentration to the scrubber equals to 971/7 mg/m^3, C3: outlet dust concentration of the stack equals to 13.58 mg/m^3, Q: Volumetric flow rate equals to 85000 m^3/hr [1].

According to the main study data, the collected dust mass of the collectors can be calculated according to relations 1 and 2.

Relation No. 1:

$$C_i - C_o = C_s$$

Where

C_i , C_o and C_s are inlet dust concentration, outlet dust concentration and collected dust concentration of the collectors $\left(\frac{mg}{m3}\right)$, respectively.

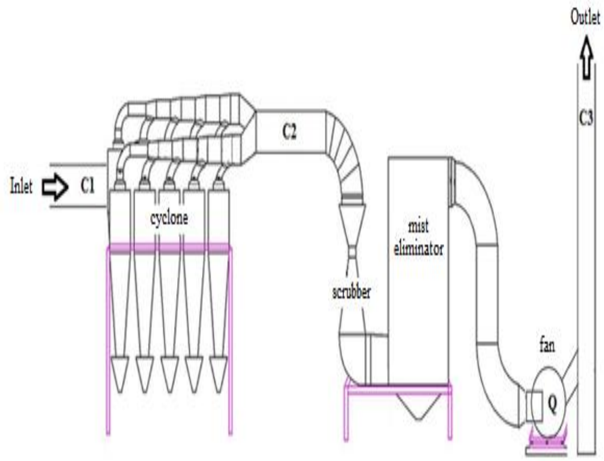
Relation No. 2:

$$C_s \times Q = \dot{m}$$

Where

Q Is inlet airflow rate of the collector $\left(\frac{m3}{hr}\right)$ and $\dot{m}$ is the mass flow rate of collected dust $\left(\frac{mg}{hr}\right)$

Fig. 1: Schematic View of the Local Exhaust Ventilation System Designed for the EAFs



To determine the chemical compositions of the EAF dust, XRD is used. For this purpose, sampling was made from the outlet dust of cyclone hopper and collected dust of the exhaust fan outlet. After the samples' preparation, they were placed in an XRD device (Philips, Netherland). The diffraction pattern was set in the range of 2θ angle equals to 5-90 degrees and analysis was performed using PC-APD Diffraction software. After determining the percentage of chemical compositions of dust in the EAFs, applying Relation No. 3, the weight of each component of dust in the cyclone hopper and the exhaust fan outlet was calculated.

Relation No 3.

$$\dot{m} \times f = \dot{m}_c$$

Where

f Is a fraction of components of collected dust and $\dot{m}_c$ is the mass flow rate of collected dust components $\left(\frac{mg}{hr}\right)$

RESULTS

The concentration results of the inlet and outlet dusts of the collectors and the amount of collected dust in the cyclone and the scrubber drainage are presented in Table 1. The results show that 232.76 kg of dust is deposited in the cyclone hopper per hour. Also, the mass flow rate of collected dust at the scrubber drainage is 81.44 kilograms per hour.

Table 1: Results of concentration of inlet and outlet dusts of collectors and mass flow rate of collected dust

Collector	Inlet dust concentration (mg/m^3)	Outlet dust concentration (mg/m^3)	Collected dust concentration (mg/m^3)	Airflow (m^3/hr)	the mass flow rate of collected dust (kg/hr)
Cyclone	3710	971.7	2738.3	85000	232.76
Scrubber	971.7	13.58	958.12	85000	81.44

The results of determining chemical compositions of the collected dust in the cyclone hopper and the outlet dust of the exhaust fan (dust inlet to the environment) are presented in Table 2. The results show that 54.14% of the collected dust in the cyclone and 48.85% of the dust inlet to the environment is Fe_2O_3.

Table 2: Results of determining chemical compositions of the EAF dust in the cyclone hopper and the exhaust fan outlet

Chemical Compositions	Cyclone Hopper		Exhaust fan Outlet	
	Percent (%)	Weight (kg/hr)	Percent (%)	Weight (kg/hr)
Fe_2O_3	54.16	126.06	48.852	6.63
CaO	14.165	33.67	8.368	1.14
MgO	8.973	20.88	6.298	0.85
SiO_2	8.311	19.34	10.783	1.46
Na_2O	4.946	11.51	ND	ND
Al_2O_3	2.392	5.57	2.679	0.36
MnO	1.989	4.63	2.984	0.41
Zn	1.7	3.96	11.956	1.62
K_2O	0.993	2.31	2.588	0.35
P_2O_5	0.913	2.12	0.574	0.08
SO_3	0.591	1.37	1.81	0.24
Cl	0.265	0.62	2.079	0.28
TiO_2	0.207	0.48	0.267	0.04
Pb	0.094	0.22	0.761	0.1
Ni	Trace	Trace	Trace	Trace
Cr	Trace	Trace	ND	ND
Cu	Trace	Trace	ND	ND
Y	Trace	Trace	ND	ND
Cd	Trace	Trace	ND	ND
Ce	Trace	Trace	ND	ND
Zr	Trace	Trace	Trace	Trace
Rb	Trace	Trace	Trace	Trace
Sn	Trace	Trace	Trace	Trace
Sr	Trace	Trace	Trace	Trace
Br	ND	ND	Trace	Trace
Ir	ND	ND	Trace	Trace

ND: Not detected

XRD patterns of collecting dust in the cyclone is shown in Fig. 2.

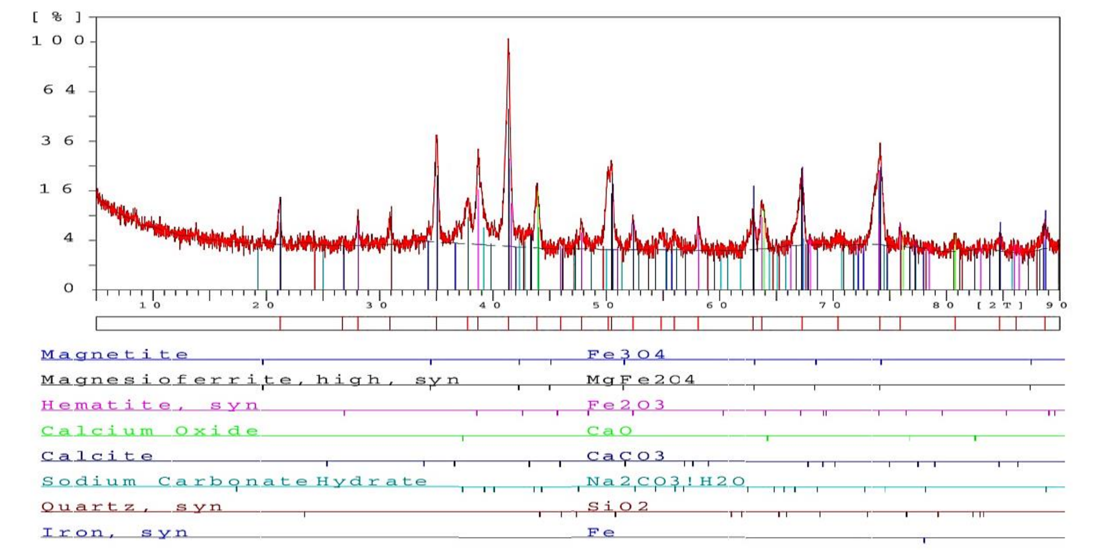


Fig. 2: XRD patterns of collecting dust in the cyclone

DISCUSSIONS

The studied results of the collected dust mass in the cyclone hopper showed that 232.76 kilograms of dust are deposited per hour which is very important in terms of cost and ecosystem. The results of XRD show that more than half of this dust is Fe_2O_3. Also, three compounds of CaO, MgO and SiO2 form more than 30% of the composition of the dust collected in the cyclone hopper and the remaining is less than 15%.

Some heavy metals existed e.g. Zn, Si and Pb, are very valuable and can be retrieved using hydrometallurgy and pyrometallurgy methods [6, 11]. A portion of the dust which is not economically cost-effective can be applied in industries such as asphalt, cement, concrete, ceramic, glass and agriculture [12, 13]. Iron oxide, due to its red colour, is one of these compounds which is used in many industries, such as painting, plastics, ceramics, paper, pipes, glass, etc. [14].

Lack of reuse of this dust can contaminate the environment. Ardashiri and Hashemi reported high concentrations of heavy metal in indoor dust that could be toxic to children [15].

The difference between the concentration of inlet and outlet dust of venturi scrubber shows that for each cubic meter of air passes through the scrubber, 958.12 mg of dust enters the detergent (water). By considering the ventilation system flow rate, the dust mass enters the water is 81.44 kilograms per hours. Water pollution occurs when dust containing heavy metals enters the water and if the existed sewage enters the environment without treatment, it leads to environmental pollution [16]. Baseri *et al*. reported that consuming food contaminated with heavy metals can cause cardiovascular diseases, depressed growth, impaired fertility, nervous and immune system disorders, increased spontaneous abortions, and elevated death rate among infants [17].

The analysis of the chemical compositions of the outlet dust from the exhaust fan existed in the environment was also demonstrated that more than half of the outlet dust consists of Fe_2O_3. Also, CaO, MgO, SiO_2 and Zn compounds form more than 35% of the composition of the outlet dust, and the remaining is less than 15%.

The Iranian Department of Environment has reported the exposure limits of 100 mg/m^3 of outlet particles from the stack of steel mills equipped with an EAF [18]. Although the concentration of the outlet pollutant from the existing industrial stack is lower than the allowed level; however, emissions such as quartz with the amount of 1.46 kg/hr and other compositions are important in terms of health and environment.

CONCLUSION

The results of this study showed that the EAF dust consists of a wide range of elements with different concentrations. The study results of the mass of the chemical compound existed in the cyclone hopper and the scrubber drainage also showed that the reuse of some elements is not only economically feasible but also has positive environmental and health effects.

ETHICAL ISSUES

The author confirms that this paper does not cite others and not published in other journals.

CONFLICT OF INTEREST

We affirm that this article is the original work of the authors and have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS
All authors participated in all stages of the research.

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REFERENCES
[1] Garkaz A, Ghorbani Shahna F, Assari M, Faradmal J. The designing and assessment of a local exhaust ventilation system coupled with hybrid collectors for dust control an alloy steel company. Iran Occupational Health Journal. 2015; 12(1):38-46.
[2] Tourang H, Amirshaghaghi H, Esmaeili M, Roshan A. Numerical investigation of fume extraction systems of electric arc furnaces. Modares Mechanical Engineering. 2011; 11(4):41-52.
[3] Chen W-S, Shen Y-H, Tsai M-S, Chang F-C. Removal of chloride from electric arc furnace dust. Journal of Hazardous Materials. 2011; 190(1):639-44.
[4] Machado JG, Brehm FA, Moraes CAM, Dos Santos CA, Vilela ACF, Da Cunha JBM. Chemical, physical, structural and morphological characterization of the electric arc furnace dust. Journal of Hazardous Materials. 2006; 136(3):953-60.
[5] Machado JG, Brehm FA, Moraes CAM, Santos CAd, Vilela ACF. Characterization study of electric arc furnace dust phases. Journal of Materials Research. 2006; 9(1):41-45.
[6] Oustadakis P, Tsakiridis P, Katsiapi A, Agatzini-Leonardou S. Hydrometallurgical process for zinc recovery from electric arc furnace dust (EAFD): Part I: Characterization and leaching by diluted sulphuric acid. Journal of Hazardous Materials. 2010; 179(1):1-7.
[7] Hesam G, Ghorbani Shahna f, Bahrami A. Survey of air pollutants emitted from rendering plant of poultry slaughterhouse and design of local ventilation system and suitable collector for control and treatment of air pollutants. Iranian Journal of Health and Environment. 2015; 7(4):469-80.
[8] Hesam G, Khakbaz G, Moradpoor Z. Design and implementation of local ventilation system on the dust control in the cramp unit of industrial poultry slaughterhouse. Journal of Sabzevar University of Medical Sciences. 2015; 22(3):342-49.
[9] Tsubouchi N, Hashimoto H, Ohtaka N, Ohtsuka Y. Chemical characterization of dust particles recovered from bag filters of electric arc furnaces for steelmaking: Some factors influencing the formation of hexachlorobenzene. Journal of Hazardous Materials. 2010; 183(1):116-24.
[10] Ruiz O, Clemente C, Alonso M, Alguacil FJ. Recycling of an electric arc furnace flue dust to obtain high grade ZnO. Journal of Hazardous Materials. 2007; 141(1):33-36.
[11] Orhan G. Leaching and cementation of heavy metals from electric arc furnace dust in alkaline medium. Hydrometallurgy. 2005; 78(3):236-45.
[12] Alsheyab MA, Khedaywi TS. Effect of electric arc furnace dust (EAFD) on properties of asphalt cement mixture. Resources, Conservation & Recycling. 2013; 70:38-43.
[13] Bakkar A. Recycling of electric arc furnace dust through dissolution in deep eutectic ionic liquids and electrowinning. Journal of Hazardous Materials. 2014; 280:191-99.
[14] Xu P, Zeng GM, Huang DL, Feng CL, Hu S, Zhao MH, *et al.* Use of iron oxide nanomaterials in wastewater treatment: a review. Science of the Total Environment. 2012; 424:1-10.
[15] Ardashiri S, Hashemi SE. Health risk assessment of heavy metals in indoor dust from Bushehr, Iran. Iranian Journal of Health, Safety and Environment. 2018; 5(2):966-71.
[16] Ahmaruzzaman M. Industrial wastes as low-cost potential adsorbents for the treatment of wastewater laden with heavy metals. Advances in Colloid and Interface Science. 2011; 166(1):36-59.
[17] Baseri E, Alimohammadi M, Nodehi RN, Nazmara S, Gorji MEh. Determination of Heavy Metals through Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) in Iranian Cheese and Their Potential. Iranian Journal of Health, Safety and Environment. 2017; 5(1):936-43.
[18] Shaeri AM, Rahmati AR. human environmental laws, regulation criteria and standards. 1st ed. Tehran: hak press; 2012.