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Original Article

Characterization and mass balance of trace elements in an iron ore sinter plant

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ABSTRACT

Environmental legislation is becoming more restrictive in several industrial sectors, especially in the steel industry, which is well known for its large pollution potential. With the recent growth of interest in effects of trace elements on the environment and health, the inclusion of emission limits on these elements in this legislation has become increasingly popular. This article aims to describe the partitioning of trace elements between the products (sinter) and plant emissions in an iron ore sinter plant, aiming to better understand the behavior of these elements in the sintering process to eventually support interventions to modify these partitions. Chemical characterization of several sintering inputs was initially performed, revealing that the steel-making residues contained large concentrations of trace elements, whereas low concentrations were observed in the flux. Based on the trace element concentrations, we analyzed the injection of trace elements in a sintering pilot using a sintering mixture. Mass balance was then used to determine the theoretical partitioning of trace elements in the sinter and emissions; cadmium, nickel, lead, mercury, and copper exhibited greater tendencies to concentrate in atmospheric emissions.

1. Introduction

The steel industry is known for its large pollution potential. With the new stricter environmental legislation, new studies have been conducted, and more precise emission controls have been implemented. The European Union, which has a very strict environmental legislation when compared to the rest of the world, has, for the steel industry, restrictive limits for a large number of pollutants; in addition, the legislation defines specific values for each process, operational condition, and abatement technology. Moreover, the limits for the concentration of SO_2, NO_2 and PM_{10} are more restrictive when compared to other countries [1]. The European legislation is also noteworthy for its efforts to introduce restrictions on the concentration of $PM_{2.5}$ in the air and for including restrictive

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limits for some trace elements such as lead, arsenic, cadmium and nickel [1–3].

Mirroring the European Union, the remainder of the world has adopted new environmental laws and revised current ones, generating greater environmental pressure on the mining and metallurgy industry. This practice is evident in China, which has shown signs of progress in their legislation [4]. For example, recently, the limits of Chinese emission were reduced drastically, from 150 mg/Nm^3 to 50 mg/Nm^3 in the case of particulate matter, and 2000 mg/Nm^3 to 200 mg/Nm^3 for SOx [5].

With the recent growth of interest in the effect of trace elements on the environment and health, the inclusion of certain emission limits for these elements has been increasingly observed as laws have evolved. From the viewpoint of environmental impacts, 14 elements are considered to have potentially higher impact: arsenic, cadmium, chlorine, copper, chromium, manganese, mercury, lead, nickel, vanadium, zinc, polonium, uranium, and thorium [6]. These elements are associated with the main inputs of the steel industry, and, when present in the sinter, can affect (positively or negatively) the steel chain and final product [7].

The gaseous emissions from a sinter plant significantly contribute toward the total emissions of an integrated steel mill and are considered the leading emitter of particulates [8]. Sintering accounts for approximately 45% of all particulate emissions of an integrated steel plant and emerges as the leading emitter of trace elements [9]. The input of these elements in the process occurs through the raw materials, which consist of iron ore, fuels, fluxes, and steel-making residues.

In this paper, for the first time, chemical characterization of trace elements in various sintering inputs was performed, and the intake of these elements in a sintering pilot was then analyzed using a sintering mixture. The mass balance was then considered to determine the theoretical partitioning of trace elements in the products (sinter) and emissions. Therefore, this study describes the partitioning of trace elements between the products and plant emissions, with the aim of better understanding the behavior of these elements in the sintering process to eventually support interventions to modify these partitions.

2. Methods

2.1. *Chemical characterization of inputs*

In the sintering process, a mixture of raw materials composed of fine ore (sinter feed), solid fuel (coke), flux, returned fines, and steel-making residues is arranged on a conveyor belt and then heated to temperatures close to 1300 °C to achieve reductive-oxidizing semifusion. The product of this process is a mass called sinter [10], which is then crushed; its particle size is adjusted through screening to meet the requirements of the next stages of steel production, and the thin material is reused in the process.

In this study, chemical characterization of various sintering inputs was conducted. These inputs were divided into 11 categories (sinter feed, pellet feed, lump, concentrate, pellet, pellet fine, lump and sinter fines, returned fines, fuel, fluxes, and steel-making residues), and the average concentrations of each trace element in each of these categories were evaluated. We then studied the concentration distribution of each trace element in each of these categories using column charts. Table 1 provides a description of the samples.

Table 1 – Description of sintering input samples characterized.

Type of sample	Origin	Number of samples
Sinter feed	Brazil	17
	South Africa	2
	Australia	13
	China	2
	India	2
Pellet feed	Brazil	5
	Canada	1
	China	17
Lump	Brazil	6
Concentrate	China	9
Pellet	Brazil	1
Pellet fines	Brazil	1
Lump and sinter fines	Brazil	1
Returned fines	Brazil	1
Fuels	Brazil	2
	China	1
Fluxes	Brazil	2
	China	5
Steel-making residues	Brazil	9
Total		97

It is not possible to include further details of the chemical analysis method since this work was conducted by two different global laboratories, ALS and SGS Geosol.

For the characterization of arsenic, cadmium, chlorine, copper, chromium, lead, nickel, vanadium, and zinc, 0.25 g samples were prepared and then digested in perchloric, nitric, and hydrofluoric acid. The obtained residue was diluted after being leached with dilute hydrochloric acid. The prepared sample was then analyzed using inductively coupled plasma-atomic emission spectroscopy (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS) using Agilent instruments; the results were corrected for spectral interferences.

For the characterization of mercury, 0.50 g samples were prepared, which were digested in aqua regia for 45 min in a graphite heating block. After cooling, the resulting solution was diluted to 12.5 ml in demineralized water. A portion of the sample was treated with stannous chloride to reduce the mercury, which was then volatilized by purging with argon before being analyzed using atomic absorption spectrometry (AAS).

2.2. *Mass balance*

In the sintering pilot, a test using the mixture described in Table 2 was conducted. The sintering pilot consisted of a conical pot, with the smallest diameter being 270 mm and the largest diameter being 300 mm, a bed height ranging from 400 to 700 mm, and a volume ranging from 25.4 to 43.9 L. The sintering temperature was approximately 1250 °C with the air flow ranging between 100 and 160 Nm^3/h. The same process adopted for the inputs was used to chemically characterize