



Multifaceted processes controlling the distribution of hazardous compounds in the spontaneous combustion of coal and the effect of these compounds on human health

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ABSTRACT

Pollution generated by hazardous elements and persistent organic compounds that affect coal fire is a major environmental concern because of its toxic nature, persistence, and potential risk to human health. The coal mining activities are growing in the state of Santa Catarina in Brazil, thus the collateral impacts on the health and economy are yet to be analyzed. In addition, the environment is also enduring the collateral damage as the waste materials directly influence the coal by-products applied in civil constructions. This study was aimed to establish the relationships between the composition, morphology, and structural characteristics of ultrafine particles emitted by coal mine fires. In Brazil, the self-combustions produced by Al–Ca–Fe–Mg–Si coal spheres are rich in chalcophile elements (As, Cd, Cu, Hg, Pb, Sb, Se, Sn, and Zn), lithophile elements (Ce, Hf, In, La, Th, and U), and siderophile elements (Co, Cr, Mo, Fe, Ni, and V). The relationship between nanomineralogy and the production of hazardous elements as analyzed by advanced methods for the geochemical analysis of different materials were also delineated. The information obtained by the mineral substance analysis may provide a better idea for the understanding of coal-fire development and assessing the response of particular coal in different combustion processes.

1. Introduction

A long exposure of coal fire to air is a well-known phenomenon (Dias et al., 2014; Ribeiro et al., 2010). This natural phenomenon primarily occurs due to the release of heat through a large surface of active sites in coal, which strongly interacts with dioxygen, resulting in a significant increase in temperature in coal power plants.

In coal fires, Al–Ca–Fe–Mg–Si spheres are generated because of thermogeochemical conversions and phase transformations of Fe-bearing minerals present in original coals (Dias et al., 2014; Sehn et al., 2016). As temperature fluctuates from 400 to 1600 °C, several active progressions occur during the self-combustion of coal, such as the release of hazardous volatile substances from the coal, as well as reactions such as oxidation of sulfides, decomposition of carbonates, and dehydroxylation of hydroxides, and hydrated sulfates. The iron-bearing phases may experience alterations during coal fires, and small crystalline phases such as jarosite, goethite, maghemite, magnetite, and

hematite could be formed or even interact with other substances such as clay mineral residues to form an amorphous, iron-bearing aluminosilicate glass. Iron mostly exists as Fe²⁺ at high temperatures in a reducing environment. Under these conditions, iron as Fe²⁺ may also be involved in the formation of low-temperature eutectics over a wide range of compositions in the Al–Ca–Fe–Mg–Si system (Bryant et al., 1997). These thermogeochemical reactions may change, which may lead to the melting of an inorganic substance in the carbon matrix.

A large number of Fe phases, such as hematite, magnetite, maghemite, Fe²⁺ silicate, Fe³⁺ silicate, and Ca and Ca–Mg ferrite spinel, and some accessory iron-bearing minerals, such as martite, mushketovite, wustite, ilmenite, chromite, native Fe, Mn ferrite, ferrosilicon, and Fe hydroxides, have been distinguished in magnetospheres as a result of the multifaceted developmental process of magnetospheres in coal power plants (Magiera et al., 2011; Dai et al., 2014). The proportion of Fe-bearing minerals in magnetospheres fluctuates with the different types of coal ashes collected from different power stations, which

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substantially depends on the feeding and combustion of coals (Yang et al., 2014).

Several studies, such as Saikia et al. (2015), Bryant et al. (1997), Magiera et al. (2011), and Dai et al. (2014), have reported the transformation process of Fe-bearing inorganic phases in coal combustion. However, there is still a lack of the methodical approach of analyzing geochemical characteristics of Al–Ca–Fe–Mg–Si spheres, especially for magnetospheres generated by Brazilian coal fires. In order to determine the most efficient approach to assess the natural and geochemical composition of the Fe spheres present in coal fires and the Fe dispersal and its potential polluting effect if the coal area is deployed, the allocation of certain hazardous elements (HEs) in various fractions of coal fires (magnetospheres, nonmagnetic fractions, and raw coal ashes) was investigated exhaustively by combining multi-analytical techniques.

In the current rapidly changing climate, it is crucial to have a better understanding of coal fires, not only to restrain the waste of natural resources but also to reduce the side effects of fossil energy on climate change and human health. Thus the main aim of the study was to improve the process sustainability of coal usage by implementing suitable measures and technological alternatives in the coal power plant. The primary objectives of this study were as follows: (1) to authenticate a detailed analytical method including all suggested criteria for determining hazardous compounds and nanominerals in coal spontaneous combustion, (2) to determine the levels of inorganic elements in the coal power plant, (3) to compare the obtained data with those from other works within the available permissible levels, and finally (4) to consider the potential human health risks at the study location.

2. Materials and methods

2.1. Samples

This study was carried out in a corporative framework in the state of Santa Catarina in Brazil. The largest coal-fired power plant is hosted in Latin America, aiming to reduce the waste from the coal stored in warehouses and mitigate the occupational risks associated with the self-combustion of coal.

During a three-year observation period (2015–2017), the samples of

49 neoformed minerals and the overlying materials were collected from the main coal deposits of the Tractebel Suez-GDF thermoelectric plant (Fig. 1). Following previously published studies (Dias et al., 2014; Ribeiro et al., 2010), every single coal-burned sample was handled separately during chemical and mineralogical analyses. The objective was to conduct a pragmatic analysis of the existing coal waste from self-combustion in the warehouses of the thermoelectric plant. The coal-fire samples were stored in tightly sealed plastic vials or wrapped in a plastic foil and then enclosed in sealed plastic bags. The sample particle size was reduced by a milling step and then dried in a laboratory furnace at 30 °C for 36 h. Thereafter, the samples were homogenized and sieved. The additional information on sampling and pretreatment can be found in the work of Sehn et al. (2016) on nanomineralogy. The ultrafine particle samples were uniformly mixed and collected by the sample division to obtain the representative Tractebel Suez-GDF samples.

The Tractebel Suez-GDF thermoelectric plant, where this study was conducted, has not only applied a large number of initiatives to improve the quality of life of the employees and local population but also conducted an industrial visiting program for students. During one particular visit, the samples were collected from self-combustion coal (Fig. 2). In order to provide a safer environment to the representatives of the academic as well as the civil sectors, the information and reports thus collected were shared with the company staff.

2.2. Electron beam

The Tractebel Suez-GDF samples with relatively high concentrations of HEs were selected for further observations by electron microscopy considering hazardous elements that may be difficult to be detected by X-ray fluorescence (EDS). For the micro- and nanoscale assessments, the ultrafine samples were analyzed by field emission scanning electron microscopy (FE-SEM) and high-resolution transmission electron microscopy (HR-TEM). FE-SEM was applied for evaluating the geochemical composition of individual phases using EDS analyzers as it allows minerals or their mixtures to be identified in coal. It was used for in mapping of elemental distributions in the studied samples (Dalmora et al., 2016; Tezza et al., 2015). A combination of FE-SEM and HR-TEM,



Fig. 1. The location of the studied power plant.

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