



Effect of the temperature of different combustion zones in the boiler grate on changes in physical and chemical parameters of bituminous coal and slags



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ABSTRACT

This paper presents the results of a study on the influence of the temperature of characteristic zones of coal combustion in a stoker fired boiler (drying, degassing, and burn-out), on changes in physical and chemical parameters of bituminous coal and slags. This information is important as it helps identify the impact of coal properties on the accumulation of trace elements, primarily mercury, in combustion waste. The study is the continuation of research work on the impact of mercury compounds accumulated in combustion waste on the natural environment (mercury from landfills of slag, and fly ash). Studies were undertaken because no in-depth analysis of the impact of the temperature of particular zones of stoker fired boilers on the physical and chemical parameters of the post-process slag, including mercury content, had been reported in literature. Both of the coals examined, classified as bituminous coal according to the International Classification of Seam Coals and of type 32.1 according to the PN-G-97002:1982 standard, showed an average mercury content of 0.0849 µg/g. In the chemical composition determined for the ash derived from burnt coal, the dominance of SiO₂ and Al₂O₃ over other oxides was found. This feature results in the increase of the softening temperature and ash melting and, therefore, during the combustion of coal tested in a stoker fired boiler, only ash was subjected to the sintering process. Mercury content in the other examined samples taken from various locations of the stoker fired boiler (drying – 32–1050 °C, degassing – 1050–1020 °C, and burn-out – 1020–400 °C) varied from 0.0668 to 0.0009 µg/g and was determined with the use of a LECO atomic absorption spectrometer. The analyses of the elemental composition, performed with the application of XRF spectrometry, for ash obtained from samples collected from different sampling points of the stoker fired boiler showed that the largest concentration of trace elements was observed for the ash derived from the samples collected in the degassing zone (temperature range 1050–850 °C).

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1. Introduction

Global coal consumption in the energy sector is expected to gradually increase by 1.3% per annum according to the forecasts of the U.S. Department of Energy (International Energy Outlook, 2013).

Hard coal, as a sedimentary rock of organic origin, consists of three basic components: organic matter, composed of a few basic chemical elements, such as carbon, hydrogen, oxygen, nitrogen, sulfur and phosphorus; mineral matter, forming non-organic compounds, and water (Ali, Tuzen, & Kazi, 2016). Coal properties

are typical in complex colloidal systems. Hard coal is a multi-phase, microheterogeneous solid solution which is organosol, organogel or xerogel. The type of solid solution depends on the coal rank (Jasieńska, 1995).

In Poland over 90% of total electricity production is based on coal combustion. In 2015, the balance resources of hard coal in Poland amounted to 24.933 million Mg (Polish Geological Institute, 2015; Smoliński, 2007, 2011).

The combustion process in a stoker fired boiler is performed in three main zones with varying temperatures: zone of drying, degassing and burn-out (Karolczuk, 1998; Kruczek, 2001; Roga, 1954).

Therefore, during combustion in grate boilers hard coal passes through three phases: drying, degassing and burn-out of the produced coke.

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In the first section of a grate, coal is heated up by absorbing heat from the combustion chamber walls, already burning coal and air passing through the coal layer on a grate. The drying phase lasts until coal reaches a temperature of 100 °C. After releasing the moisture, the coal temperature further increases and the degassing phase takes place, during which volatile organic compounds, primarily hydrocarbons, are released. At a temperature of 350–500 °C, a release of volatile matter from successive layers of fuel and partial conversion of the produced carbon dioxide into carbon monoxide takes place. The degassing product is a coke breeze composed of carbon and mineral matter (Karolczuk, 1998; Kruczek, 2001; Roga, 1954; Szlęć, 2008). The coke breeze burns out very slowly, because of its internal structure. Therefore, the burn-out phase of coke breeze determines the time needed to burn coal.

The time of coke breeze combustion depends on the coal caking properties; the stronger the sintering, the more compact the resultant coke breeze is.

According to the Agency for Toxic Substances and Disease Registry (ATSDR, 2015), the most poisonous compounds are: arsenic, lead and mercury. This is why the question of mercury compound release in to the environment from coal combustion processes is considered to be so important.

Worldwide research carried out by UNEP (the United Nations Environment Programme) (UNEP, 2013) has shown that approximately 50% of global mercury emissions are of anthropogenic origin (stoker fired boilers and pulverized coal boilers operated in heat and power plants) (Zarzycki & Wichliński, 2014).

Mercury contained in coal is usually present in inorganic compounds, and is often associated with pyrite, in particular coarse pyrite of epigenetic origin (Ali et al., 2016; Ali, Tuzen, & Kazi, 2016). Mercury is also found in organic compounds as well as micro intrusions of metallic mercury (Dziok, Strugała, Rozwadowski, Macherzyński, & Ziomber, 2015; Kłojzy-Karczmarczyk & Mazurek, 2014; Róg, 1998; Zarzycki & Wichliński, 2014).

The impact of the combustion temperature together with the qualitative and quantitative impact of gases present in the coal combustion chamber on the rate of mercury compounds release in to the atmosphere has been described previously (Dziok, Strugała, Rozwadowski, & Okońska, 2014; Gostomczyk, Jędrusik, & Świerczok, 2010; Hławiczka, Kubica, & Zielonka, 2003; Yudovich & Ketris, 2005a, 2005b). It has been found that the emission of mercury compounds from fuels takes place immediately after putting a sample into the test furnace, at temperatures of

200–300 °C and at a temperature (300–500 °C) that corresponds with the degassing phase (Wichliński, Kobytecki, & Bis, 2011). It has been also shown that the most important parameters affecting the degree of mercury compound removal from hard coal include: the final combustion temperature, the heating rate, as well as the type and flow rate of the carrier gas. The increased gas flow rate and low heating rate enhance the release of mercury compounds from a fuel. It has been also found that mercury release is most effective in a reducing atmosphere (Dziok et al., 2014).

During the storage of solid combustion waste (slag, fly ash), water erosion takes place causing leaching of mercury compounds from combustion waste and its migration to water. The thermally processed waste has a particularly high potential for the release of toxic substances, including mercury, into the water and soil environment. Mercury may also be transported with particulate matter in the atmosphere (Ali et al., 2016; Feng, Sommar, Lindqvist, & Hong, 2002; Glodek & Pacyna, 2009; Hower, Eble, & Quick, 2005; Kostova, Hower, Mastalerz, & Vassilev, 2011; Niedźwiecki, Meller, Malinowski, & Sammel, 2007; Nowak, 2014; Pacyna et al., 2010; Sushil & Batra, 2006; Vejahati, Xu, & Gupta, 2010; Wichliński, Kobytecki, & Bis, 2012; Zhang, Zhao, Ding, Zeng, & Zheng, 2007).

Nevertheless, no in-depth analysis of the impact of the temperature of particular zones of stoker fired boilers on the physical and chemical parameters of the post-process slag, including mercury content, has been reported in literature.

The aim of this study was therefore to identify the changes in physical and chemical parameters of bituminous coal and slags during the combustion process in different zones of a boiler grate, and in particular the changes in mercury content, as well as the temperature effect on these changes. The study is considered to be important for identifying the impact of coal properties on the accumulation of mercury in combustion waste.

2. Materials and methods

Samples of coal and combustion waste were collected from different parts of a boiler grate, type WR10. Places of sample collection are presented in Fig. 1.

Tests were carried out on the stoker fired boiler WR10. This boiler is equipped with a vertical lifting fire door and a movable grate. The grate movement speed was: 1 m/6 min. The total residence time of coal on the movable grate was about 30 min (from the front section to the end of zone V). Samples were collected in

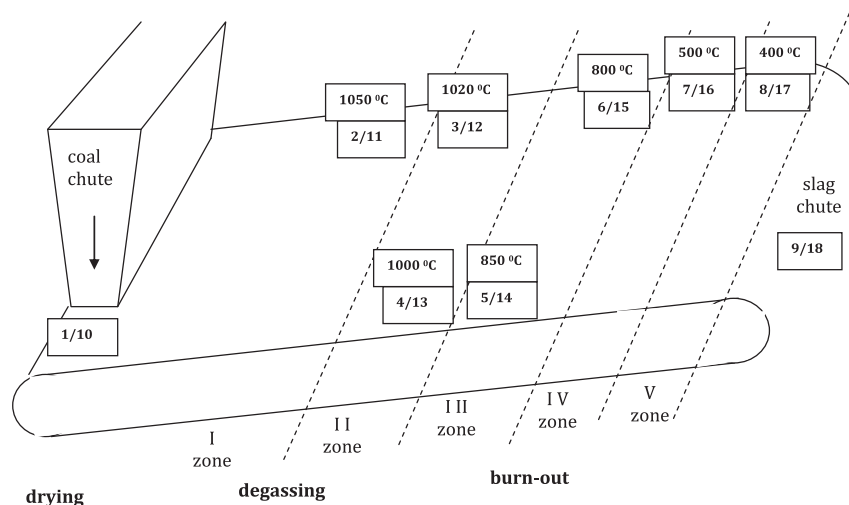


Fig. 1. Diagram of sampling points along the grate of the boiler.

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