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Original Research

Phase Minerals Composition of Wastes Formed in Bituminous Coal Combustion from Individual Domestic Furnace in the Piekary Śląskie Town (Poland)

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Abstract

The aim of this work was to present the mineral composition of ashes which were the result of burning coal in individual home furnaces in the area of Piekary Śląskie. Ashes samples were examined by X-ray powder diffraction and analytical scanning electron microscopy. Main components of the ash particles is aluminosilicate glaze containing such elements as iron, calcium, sodium, potassium, copper, lead, nickel, phosphorus, titanium, barium and sulphur. Solid waste as ashes, which were the result of the process of burning coal in individual home furnaces can be characterized by the majority of particles of the size not larger than several micrometers. These particles have mostly irregular or spherical shapes. The knowledge of phase composition of the examined waste has a great significance while estimating their influence on environment, especially when considering storage of ashes with community waste.

Keywords: coal combustion, ash, individual domestic furnace, phase minerals

Introduction

The processes of fossil fuel burning are the main source of emission of dusts to the atmosphere, simultaneously delivering solid wastes to the environment. Domestic furnaces can be divided into 3 groups. Ceramic furnaces, usually built of bricks, have as their only function the heating of habitable rooms. Kitchen stoves used for cooking and as a source of room heat typically burn low-quality coal for approximately 4-6 hours a day. The third group comprises room-heating stoves that are also sources of hot water [1].

Estimative data show that the number of home furnaces, which are not equipped with the furnace gas dedusting devices is of about 7 million in Poland. 14 million tons of coal are burnt annually in home furnaces in Poland [1].

The range of pollution caused by the low emission is difficult to estimate and its reduction is extremely complicated. But it is only one of the negative factors in the process of burning solid fuels in individual home furnaces. Solid waste, mainly ashes, are another factor whose only way of utilization is storage on the communal waste dump.

Changes coming in the processes of solid fuel combustion are important factors deciding about hazards of energy industry wastes. Dust containing harmful substances (Cu, Pb, Cd, Ni, Cr and Zn, sulphur oxides and nitrogen) is mainly emitted by low chimneys of individual one- and many – family houses. These buildings have not any dedusting devices and emission from these sources many times exceeds norms, particularly in a heating season [2]. Solid wastes are deposited in municipal dump grounds or participate in a secondary circulation, that is they are passed to a furnace chamber of boiler once again.

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Anthropogenic pollutants cause degradation of natural environment, they affect negatively both living organisms and material goods. The dust pollutants are one of the most menaces to human health as a of result mechanical aggravation of skin, mucous membranes, conjunctivas as well as the different kinds of complication in the metabolic system [3-4].

Solid wastes from power plant are significantly different to wastes from individual house furnaces in their chemical composition, and the morphology of their particles [5-8]. It is related to type of solid fuel, as well as to the process of its combustion.

Investigative Material

The investigated material comprised ashes formed in bituminous coal combustion in individual house furnace located in the Piekary Śląskie (Dąbrówka Wielka, Brzozowice Kamień and Dołki) town situated in the easternmost part of Silesia (Poland). Geographical co-ordinates defining the town location are as follows: 50º25' of northern latitude and 18º52' of eastern longitude. The whole town area is situated in the northern part of the Upper Silesia Industrial Region [9].

Separate samples (total amount – 12) were collected twice a month from each furnace during winter season, in the heating time of 2005/2006. Samples were taken from ash-pans under hand-fired grates. In the case of every furnace, the average daily use of coal was about 42 kg and, from each, 8 kg of ash resulted. The samples collected from individual furnaces were never mixed.

Bituminous coal (peas) from "Piekary" Mining Plant was being burnt there. Bituminous coal was combusted in the boilers of the Zębiec SWK -21 and Unical type, built of a steel welded water trunk. Indicative thermal power in dependence from stove carried out 20-24 kW and admissible pressure 0.2 MPa. Temperature of combustion gas in boilers was from 160 to 270ºC.

Methods of Investigation

Qualitative phase analysis of ashes and bituminous coal was carried out with the method of scanning electron microscopy using Philips XL 30 TMP under analytical conditions such as acceleration voltage 15 kV, beam current intensity 20 nA and equipped with EDAX EDS Sapphire system. Analyses were performed on carbon rings and polished pellets – the samples were mounted in epoxy resin.

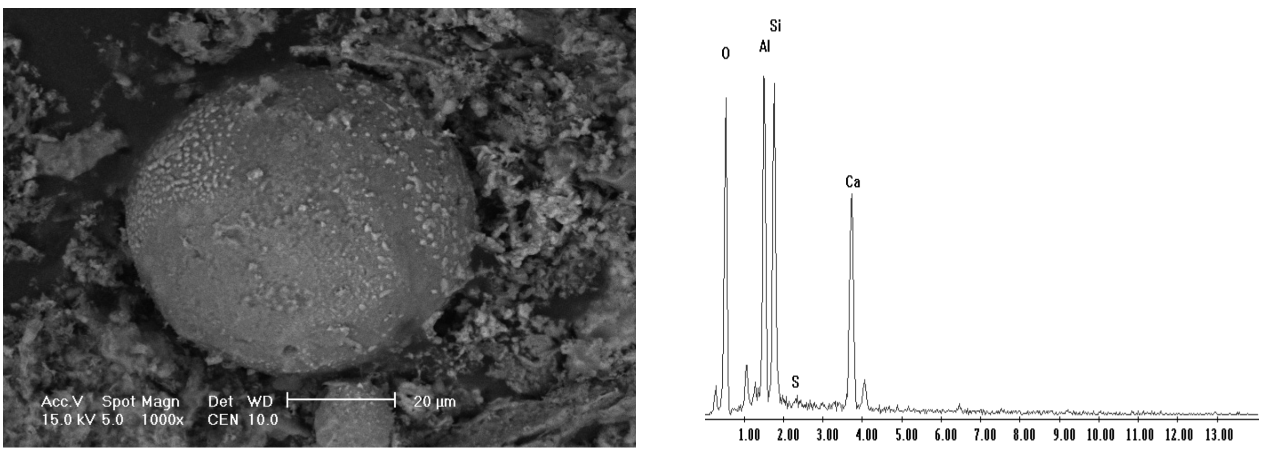


Fig. 1. SEM image with EDS spectrum of aluminosilicate particle in ash from domestic furnace.

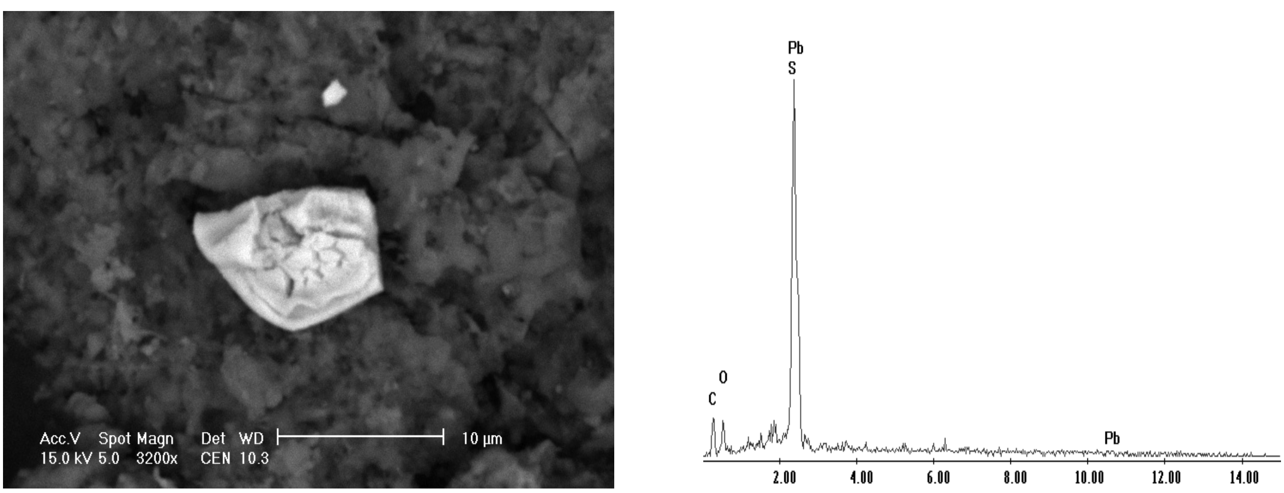


Fig. 2. SEM image with EDS spectrum of PbS in ash from individual domestic furnace.

The samples were examined by X-ray powder diffraction using Co-Kα_1 (from graphite monochromator) radiation in Philips PW 3710 diffractometer to determine the abundance of the most common crystalline components of the ash. The time of impulses counting in the step method was 3 second (per a step), counter speed was 0,02º per minute, lamp voltage – 45 kV and current intensity – 30 mA.

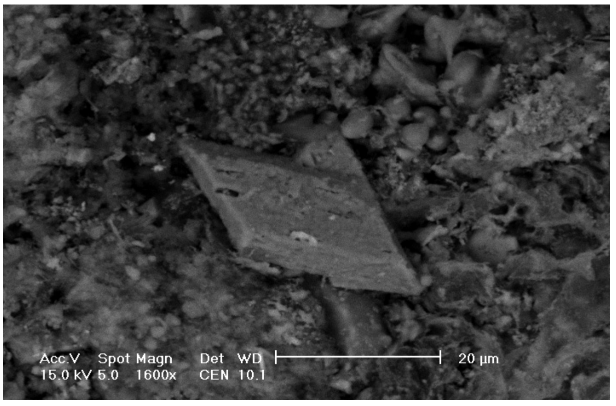


Fig. 3. Gypsum twin in ash from domestic furnace.

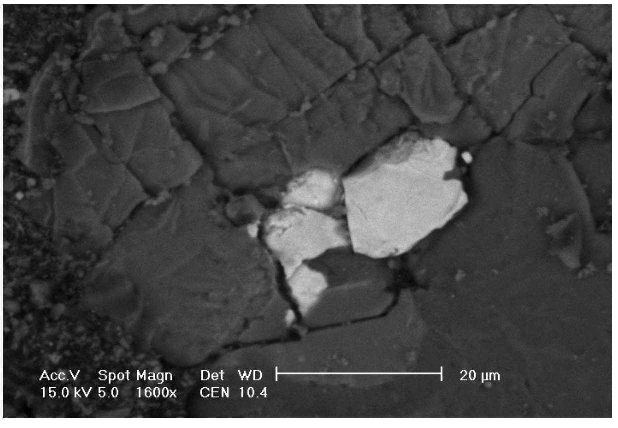


Fig. 4. Barite particles (white points) in ash from domestic furnace.

Results and Discussion

Investigations made enabled to find the phase composition of wastes formed in the process of bituminous coal combustion in individual furnace in the Piekary Śląskie town. In the studied samples of ashes diffractograms show high background and a hump, characteristic for amorphous substance, with maximum at 26º-27º 2θ and 20º-50º 2θ.

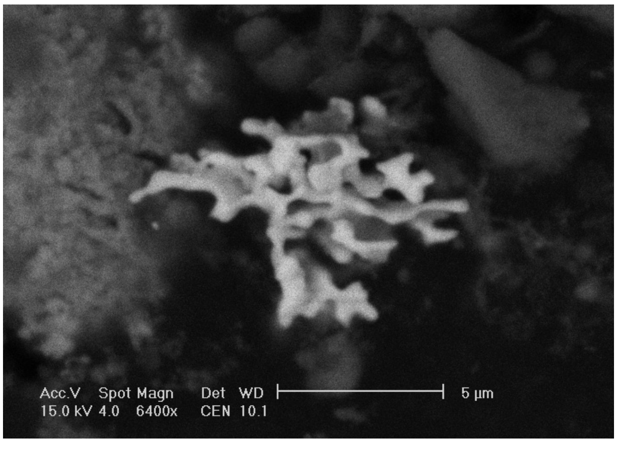
X-ray diffractive analyses show that the amorphous phase makes up about 60 vol.% of the waste. The estimate was obtained using the Rietvelda method. Crystalline aluminosilicates dissolve with difficulty. However, in their amorphous form, they are more soluble. The degree of solubility depends on the prevailing pH, temperature and the size of the ash particles.

Amorphous glaze substance is present in the examined samples of ashes, which makes the characteristic projection on diffraction patterns. Problems with phases' identification appear also when there were more than six of them in the sample (peaks interlay on one another) and these, which occur in 2-5% do not appear on diffraction patterns or they have appeared only as single reflections. Literature data concerning minimum detectable amount of different materials in a given sample confirm this fact [10].

Among marked crystal phases in the examined ash samples there occur anhydrite, gypsum, hematite, magnetite, goethite, quartz, calcite, mullite, periclase, kaolinite, dolomite, piryte, sphalerite, galena, feldspars (albite-anorthite).

The samples were observed by scanning electron microscopy (SEM). Among the anthropogenic components of wastes from individual furnaces particles the aluminosilicates with variable content of sodium, potassium, calcium and iron occur in the highest number. Their forms are mostly pointed, bar-like or spherical, while their surfaces are usually porous. Particle sizes are up to 100 µm (Fig. 1). Spherical forms reflects burning processes [11-13].

Sulphides are the most numerous group identified in studied samples of ashes. Among them galena, ZnS substance and pyrite were identified. Galena particles are of a very small sizes (up to 10 µm) with pointed and tabular forms (Fig. 2).



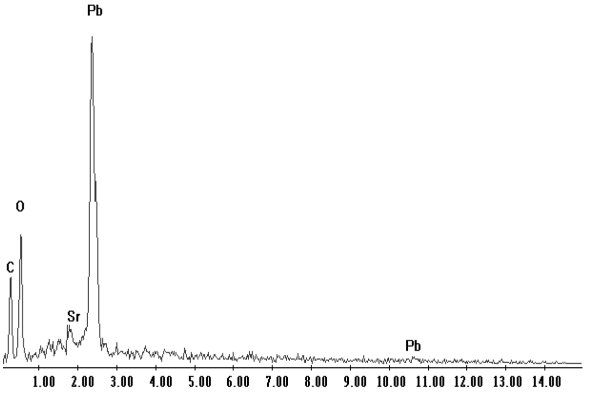


Fig. 5. $PbCO_3$ particle in ash from individual domestic furnace with EDS spectrum.

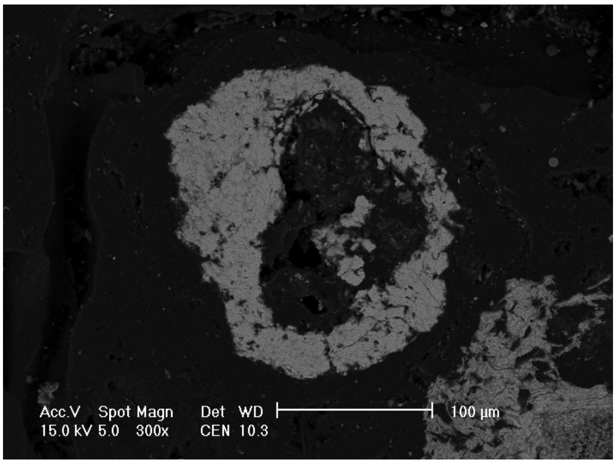


Fig. 6. SEM image of iron oxides particles in ash from domestic furnace.

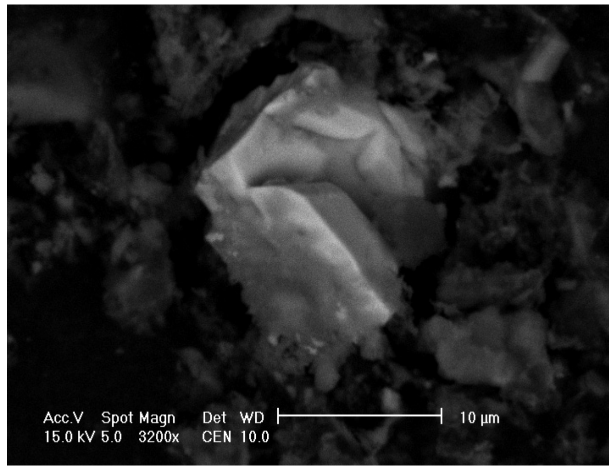


Fig. 7. SEM image of monazite particle in ash from domestic furnace.

ZnS substance occurs mostly as sphalerite, which aggregates of a few tens micrometers often are found together with galena. Pyrite particles (partially oxidized) have irregular forms, sizes up to a few several hundreds of micrometers and occur in lower quantities then in the bituminous coal samples studied.

The next occurring components of ashes are numerous calcium and barium sulphates. Calcium sulphate is found as gypsum ($CaSO_4{\cdot}2H_2O$) and showes variable forms. Tabular particles are often observed with twinning called swallow's tails (Fig. 3). They are of tens microns in a size. Barite occurs in a form of solid aggregates with smooth surface. Barite containing admixture of Mg, Ca, Si, Al and Na was identified. The form of these particles is usually irregular, there traces of digestion and their size is the range of a few up to several tens of micrometers (Fig. 4).

Carbonates are among the main of ashes constituents investigated. Lead carbonate $PbCO_3$ predominates here, showing irregular and pointed particles. They are the most often laced (open-work) and dendritic, and their size is up to several micrometers (Fig. 5). The accessory representative of carbonates is dolomite $CaMg(CO_3)_2$, which occurs in a form of elongated and rough surfaces, with a size often higher then 100 μm.

Iron oxides are also numerous components of ash, among them hematite in a crystalline form and amorphous form. In the case of crystalline forms, the shape of particles of iron oxides is usually pointed and oval or spherical (microspheres) in the case of the amorphic form (Fig. 6). Particle surfaces are usually smooth, and their sizes are about a few tens of micrometers. They often form aggregates.

Among accessory phases found in the ashes calcium and rare earth's elements phosphates were identified together with zirconium compounds such as silicates and oxides. In the group of rare earth's elements phosphates mainly cerium monazite was identified mainly (Ce, La, Nd, Th, Ca) $[PO_4]$. Its particles show a solid, irregular form, and their size is about several micrometers (Fig. 7).

The accessory components are also copper and zinc compounds, forming usually aggregates of tabular shapes and several micrometers in size. Single particles containing Cu, Zn and Ni are of less then 1 μm and are difficult to analyze.

Conclusions

The variable phase composition of wastes from individual house furnaces showing high content of amorphous phase better soluble in aquatic environment than its crystalline equivalents are hazardous to the environment. Low temperature of combustion causes that phases difficult to analyze are formed, and many particles are less then 2 μm sizes in size.

Solid wastes are deposited in municipal dump grounds or participate in a secondary circulation, that is they are passed to a furnace chamber of boiler once again. Their deposition in storage places can have negative influences on water and soil because of their granulometric and mineral composition as well grain morphology.

However, combustion and chemical working of municipal wastes is still only marginally viable. Minimization of waste quantities and the equipping of dumps for waste segregation and safe storage are major aims of the Silesian Voivodship within which Piekary Śląskie is located. It is also important to note that many home furnaces are old and coal of poorer quality tends to be used in them.

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