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Short Communication

Physical Properties of Ash from Co-Combustion of Coal and Biomass

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Abstract

This article presents the tests of fly ash properties which originated from co-combustion. The ash samples for testing came from Polish combined heat and power plants co-firing different types of biomass with hard coal in pulverized and fluidized beds. For comparison purposes, the properties of fly ash from coal combustion also were examined. Measured properties include grain composition, specific density, bulk density, and grain shape. Statistical analysis of results did not demonstrate the influence of biomass on the ash properties.

Keywords: biomass, co-combustion, fly ash

Introduction

Environmental policy in most countries is still developing. Newer and stricter regulations and requirements aim at improving natural environment conditions. Changes have not omitted the energy sector producing electricity and/or heat. In many countries energy is still produced mainly from hard coal and lignite combustion. Relative environmental protection, and technical and economical conditions result in co-combustion of fossil fuels with biomass or waste fuels in power boilers.

The type of co-fired biomass used by individual power plants depends mainly on the occurrence of timber or agricultural industry in a given area, and the cultivation of specially adapted energy crops or transportation costs. The most often co-fired biomasses include wood, bark, wood chips, corn straw, rapeseed straw, olive pulp, olive kernel, and herbaceous biomass [1, 2]. Co-fired wastes include sewage sludge, coal tailings, petroleum coke, and tire-derived fuel [3-5].

Co-combustion of biomass with fuels protects natural fuels resources and allows us to develop waste, reduce greenhouse gas emissions, and reduce toxic metals and sulphur emissions [6, 7]. But there is also negative side. One of the problems is slagging and fouling because of relatively low melting temperatures characteristic of biomass ash, and corrosion of boiler surfaces [8, 9]. The problem may also be the variation of biomass moisture content – the differences in calorific value of a given sort of biomass and low bulk density, which has an influence on transportation costs and storage areas.

The properties of fly ash from co-combustion depend mainly on combustion conditions (type of boiler, temperature), amount and chemical composition of ash from the coal and biomass and contribution of biomass in the mixture with coal [1, 10]. Fly ash from biomass is more varied from coal fly ash. This is mainly due to the existence of many types of biomass, depending on origin: forestry, agricultural, herbal, and others. Even in the case of the same type of biomass there may be several differences in properties of fly ash caused by other places of origin, differences in cultivation, applied water, and storage [11]. Also, the amount of produced fly ash depends on the type of burned biomass [1, 9]. In addition, insufficient knowledge about properties of solid residues from the combustion of coal and individual types of biomass in order to be able to predict the

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properties of fly ash from co-combustion [6, 12]. Therefore, it is important to carry out studies of originated fly ash for different types of fuel mixtures. This allows us to adjust the fuel mixture which, when burned, gives the fly ash required properties that have a definite impact on further directions for their utilization.

The studies on directions of use of fly ash from biomass and coal co-combustion have been the subject of many publications. Due to the properties similar to ash from hard coal, the research is mainly on the possibility of their use in the production of cement [1, 13], concrete [14], ceramic materials [1], and adsorbents [11].

The purpose of our article is the characterization of the physical properties of ash from co-combustion of coal with different types of biomass in fluidized and pulverized beds.

Materials and Experimental Methods

The fly ash from co-combustion of hard coal and biomass combined and heat power plants were studied in Poland. The samples were taken by use of electrofilters. The following factors were taken into account: type of boiler (pulverized (P), fluidized (F)), exhaust desulfurization methods (ash without (-) and with products from desulfurization (S)) and different types of biomass. The participation of biomass in fuel equaled from 7 to 17%. To determine the impact of biomass on the properties of fly ash, one measured the ash from combustion of hard coal itself in pulverized and fluidized beds.

The composition of the grain size of fly ash was determined by laser diffraction method by means of a Fritsch Analysette 2 apparatus. Specific density was determined with the pycnometric method using a helium Micrometrics Multivolume Pycnometer. Specific surface was determined according to the PN-EN 196-6:2010 standard using Blaine's apparatus. Bulk density was measured according to the PN-S-96035:1997 standard. The morphology studies of the fly ash grains were also carried out. The research was conducted based on analysis of the photos taken using a scanning electron microscope. The computer analysis of pictures was carried out using Aphelion software. The basic geometrical properties of grains were determined, including one of the grain shape coefficients – circularity coefficient describing roundness of the grains. This coefficient takes a value equal to 1 for spherical objects.

Results and Discussion

The particle size range of ash is in the range of 0-550 μm. The differences between individual types of ash are relevant to grain size distribution. The ash samples P1, PB1, PB3, and PS were characterized with thicker graining in whole measure range. Samples P2 and PSB contained higher amounts of small grains, but also a large population of thick grains. Samples PB2, FS, and FSB were characterized with fine graining. The largest grain content (in the range of 300-500 μm) was negligible – 2%, while the content of the finest grains (0-63 μm) was the largest, reaching 54%. There was no correlation between the graining of ash and exhaust desulfurization method and biomass participation. What was observed was finer graining of fly ash originating in fluidized beds (samples FS and FSB). The average size of grains for ash is presented in Table 1.

The specific density of fly ash reached 2.08-2.51 g/cm^3. The lowest density was represented by ash obtained in a pulverized bed with co-combustion of biomass and with participation of exhaust desulfurization products (sample PB3). The highest density characterized the ash from fluidized bed without biomass (FS) – 2.51 g/cm^3 – and with biomass participation (FSB) – 2.38 g/cm^3.

The bulk density (volumetric) is strongly linked with specific density of fly ash. The PB3 sample was characterized by highest bulk density (0.96 g/cm^3). The ash from fluidized bed whose specific density, was the highest had the smallest values of bulk density 0.47 g/cm^3 and 0.63 g/cm^3, respectively, for FS and FSB.

The results of tests of specific surface area of fly ash obtained by Blaine flow method were diverse and ranged from 2547 to 7,050 cm^2/g. The most extensive surface was characteristic for ash from fluidized beds.

The results for the specific density, Blaine specific surface, and bulk density are shown in Table 1.

Fly ash from pulverized beds was characterized with similar shapes of grains (Figs. 1A-1G). These samples were dominated with grains of spherical shape, and very different sizes ranging 1 to 100 μm. Except spherical grains, the mentioned ash contained small quantities of grains with irregular shapes (thin tiles, stripes), which formed a binder of spherical grains or formed crusting on them. Slightly different shapes of grains had the ash from fluidized beds (FS and FSB). The grains of these ash were characterized with very irregular shapes, Fig. 1H, 1I. They were mainly oblong, sharp-edged, rarely spherical grains.

Circular coefficients of grains (Table 1) belonging to fly ash samples P1, P2, PB1, PB2, PB3, PS, and PSB reached values from the rage of 0.854 to 0.946. The coefficients of two other samples (FS and FSB) were significantly lower and equaled 0.825 and 0.838, respectively. The results of the calculations of circular coefficient for tested ash confirmed a much higher content of spherical grains in the samples of ash from pulverized bed compared to fluidized bed. There was no impact of co-combustion of biomass on the shape of grains of the fly ash. In order to determine the impact of co-fired biomass on the physical properties of fly ash, the analysis of data clustering with the use of EM algorithm (expectation maximization) was carried out [15].

Cluster analysis (Table 1), that is object grouping, aims to divide the data set into groups in such a way that the elements in the same group were similar to each other, and at the same time different from elements from other groups. Applied EM algorithm (maximizing the expected value) calculated the probability of belonging to agglomerates assuming one or several probability distributions. The purpose of the algorithm was to maximize the general probability (data reliability) for each division into clusters. Cluster analysis performed using Statistica software has

Table 1. Results of tested fly ash samples.

Fly ash	Feed fuel	Specific density [g/cm^3]	Bulk density [g/cm^3]	Specific surface area [cm^2/g]	Average grain size [μm]	Circularity coefficient (RC1)	Clusters
P1	Hard coal (100%)	2.18	0.87	2933	114.5	0.896	1
P2	Hard coal (100%)	2.13	0.92	2845	87.2	0.946	1
PB1	Hard coal (93%)/ sunflower husks (7%)	2.16	0.85	2667	157.5	0.854	1
PB2	Hard coal (89%)/ branc corn (11%)	2.21	0.68	4023	61	0.866	1
PB3	Hard coal (90%)/ bark. wood chips (10%)	2.08	0.96	2547	118.2	0.888	1
PS	Hard coal (100%)	2.23	0.96	3758	124	0.908	1
PSB	Hard coal (90%)/ bark. wood chips (10%)	2.21	0.8	3083	89.5	0.924	1
FS	Hard coal (100%)	2.51	0.73	7050	47.5	0.825	2
FSB	Hard coal (83%)/sunflower husks (11%). bark. wood chips (6%)	2.38	0.63	4544	69.9	0.838	2

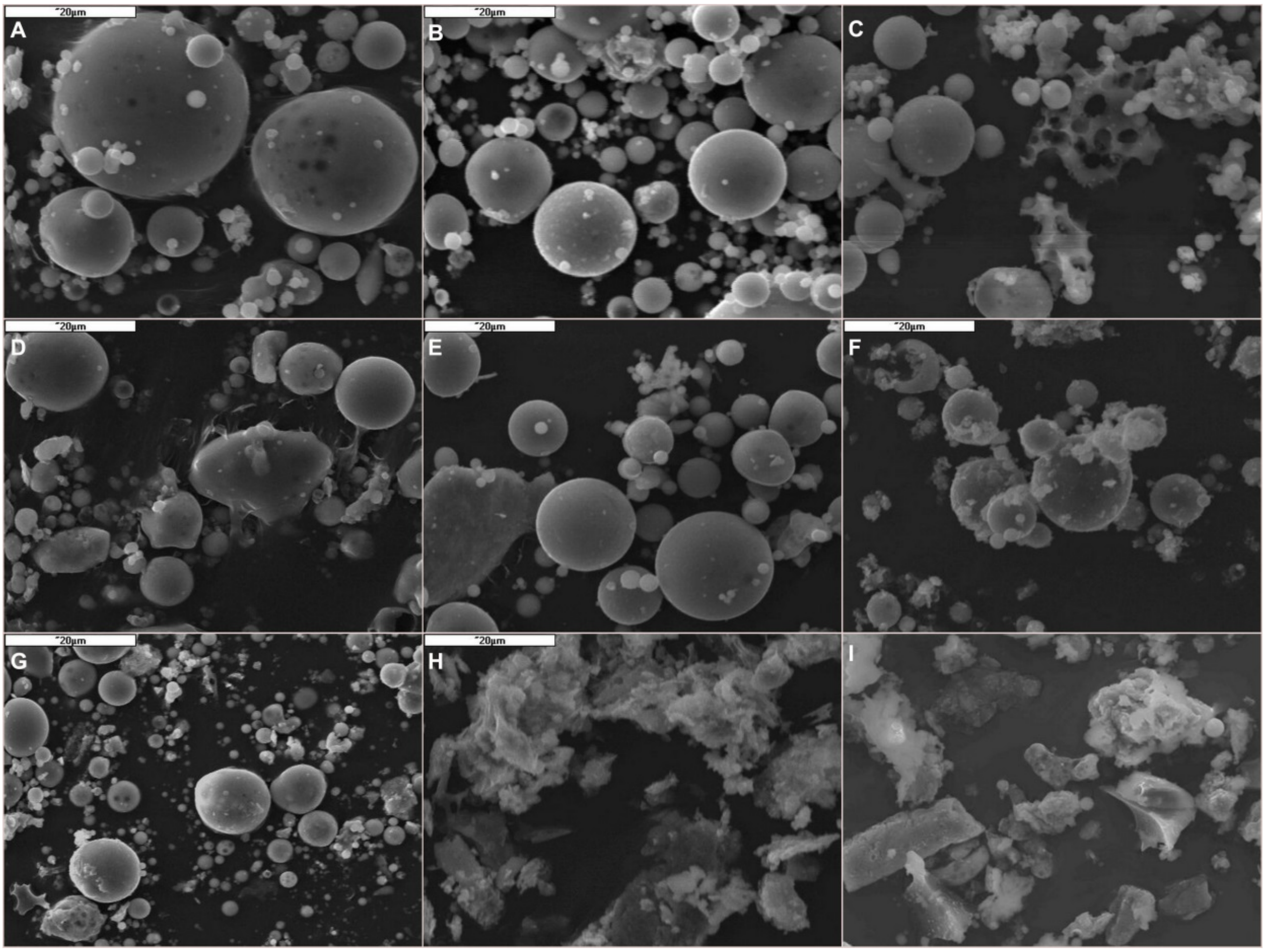

Fig. 1. Micrograph of fly ash: A-P1, B-P2, C-PB1, D-PB2, E-PB3, F-PS, G-PSB, H-FS, I-FSB.

identified two clusters by differentiating the ash from pulverized and fluidized beds. This means that the type of boiler from which the ash came had a major influence on the physical properties. The analysis has not shown clearly the impact of biomass and exhaust desulfurization products on tested physical properties of fly ash.

Conclusions

This article provides the results of studies of selected physical properties of ash obtained in co-combustion of biomass and hard coal. The participation of biomass ranged 7 to 17%. The factor that differentiated physical properties of studied ash, as statistical analysis showed, is the type of boiler in which they are produced. One confirmed the fact that the fly ash from fluidized beds compared to pulverized ones are characterized with lower bulk density and extensive specific surface area, they also differ in grain shape and size. Analysis of the results of the studies have not confirmed the relationship between measured physical properties of ash and biomass participation in co-combustion. This is the result of the amount of burned biomass in relation to coal, as well as low ash content in the biomass itself.

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