Application of Fly Ash from Biomass in Suspension Technologies

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Summary

The article presents the results of research on possibility of application of fly ash from agro-forestry biomass fluidized bed combustion for suspension technologies. For this purpose, physico-chemical properties of fly ash were examined as well as ash-water suspensions and these with the addition of cement. Potential use of suspensions in solidifying backfill and caulking gob was explored.

Keywords: biomass, fly ash, suspension technologies, mining

Introduction

The main objective of electricity and/or heat production from renewable energy sources (RES) is reduction of consumption of traditional fossil fuels resources (coal, petroleum, natural gas) and limitation of pollutants emitted to the atmosphere. Renewable energy sources include solar energy, hydropower, wind energy, geothermal energy, municipal waste, biofuels, biomass or heat of surrounding environment (using heat pumps) [1].

Conversion of biomass to energy carriers can be achieved by various physical, chemical and biochemical methods. Biomass, as an energy carrier, can be divided into solid, liquid and biogas.

Solid biomass is organic, non-fossil material of biological origin that can be used as a fuel to generate electricity or produce heat. Three types of solid biomass can be distinguished [2]:

- Wood waste from forestry and wood industry (sawdust, urban wood chips)
- By-products and waste derived from agriculture, agri-food industry and municipal industry (straw, grain, oilseeds stampings, sewage sludge, slurry)
- Tree and fast-growing grass plantations, energy crops (Salix willow, millet)

Comparing properties of coal used in power generation and biomass it should be noted, that in terms of quality the elemental composition remains the same. However, there are differences in the contribution of the various elements and chemical compounds. The average content of carbon in biomass is two times less than that in coal. Biomass has a much smaller content of nitrogen and sulfur comparing to coal, what is considered as an advantage. Simultaneously, compared to coal, biomass has a much higher content of calcium, alkalis, phosphorus, various and often high chlorine content, which can cause increased corrosion and corrosive sludge buildup in the boiler during its direct combustion [3-5]. One drawback of biomass is its high, compared to coal, moisture content. Depending on the type of biomass and duration of seasoning, moisture content can vary between 10 and 60 %. Lower calorific value is a result. In terms of energy aspect, 2 tons of biomass are equivalent to 1 ton of coal [6]. Properties of biomass determine the need for appropriate installation and technical solution to ensure its energy-efficient processing. This is done mainly through co-combustion, combustion, pyrolysis or gasification.

Type of biomass used for energy purposes depends mainly on the occurrence in a given area of timber industry and agriculture, energy crops cultivation and transport costs. For frequently used biomass one can include: wood, wood chips, bark, straw, residues from oilseeds stamping, sunflower husks [7-9].

Likewise the combustion of fossil fuels, combustion of biomass gives rise to solid wastes in the form of fly ash. Because the aim is to utilize wastes, research on possibility of using fly ash from biomass for suspension technologies has been undertaken. Suspension technologies have been successfully applied in mining industry, mainly for caulking gob and backfill solidifying [10]. These technologies use various wastes, mostly fly ash from the combustion of coal and flotation tailings from coal enrichment processes. Wastes are used for preparation of waste-water suspensions. In recent years, especially in the summer periods, there are deficits of quantities of supplied and utilized fly ash. The needs and capabilities of the mines are much higher. Hence, there are ongoing studies on the possibilities of using fly ashes from combustion of fuel different than coal, co-combustion or combustion of various wastes for suspension technologies purposes [11-14].

The article presents results of physico-chemical properties of fly ash from combustion of biomass and the possibility of using it for waste-water mixtures preparation for suspension technologies used in coal mining.

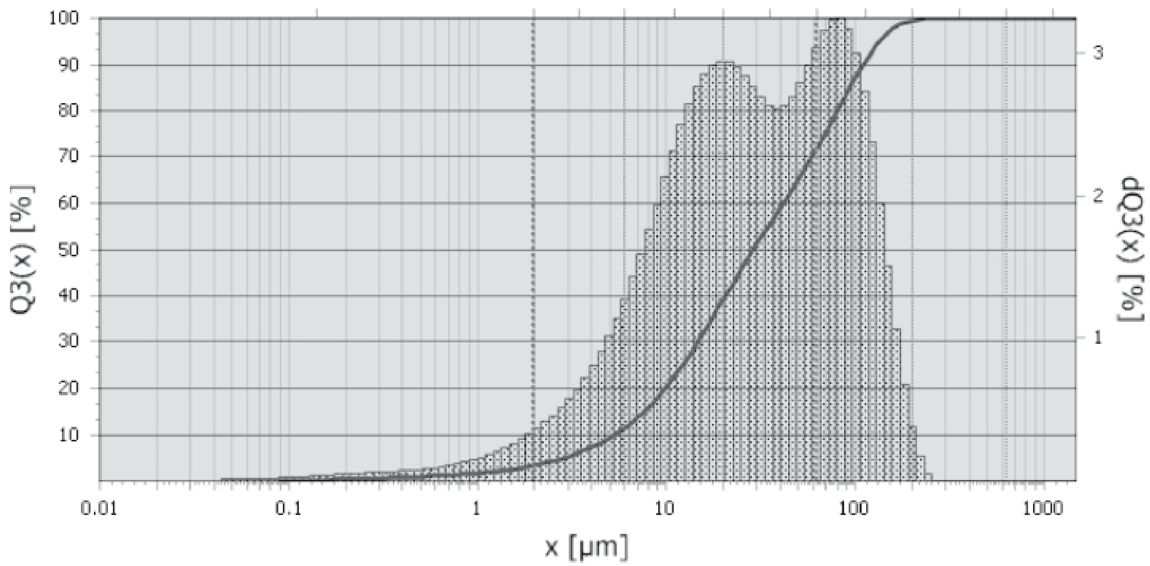

Fig. 1 Particle size distribution of ash derived from combustion of agro-forestry biomass in fluidized bed.

Rys. 1 Skład ziarnowy popiołu ze spalania biomasy rolno-leśnej w kotle fluidalnym

Tab. 1 Results of mine water analysis after purification [mg/dm^3]

Tab. 1 Wyniki analizy próbek wód dołowych oraz solanki [mg/dm^3]

No.	Pollution indicator name	Unit	Limit value according to PN-G-11011	Determined value in tested ash	Fly ash from coal combustion
1	pH	–	6,0– 12,0	12,75	12,09
2	Chlorides	mg Cl/dm^3	1 000,0	1 538,0	3 701,0
3	Sulfates	mg SO_4/dm^3	500,0	4 687,0	1 808,0
4	Arsenic	mg As/dm^3	0,2	0,0440	–
5	Chromium (III)	mg Cr/dm^3	0,5	0,2160	0,014
6	Cadmium	mg Cd/dm^3	0,1	0,0002	<0,005
7	Copper	mg Cu/dm^3	0,5	0,0030	<0,005
8	Lead	mg Pb/dm^3	0,5	0,0009	0,99
9	Mercury	mg Hg/dm^3	0,02	<0,0002	–

Subject matter and methodology

Fly ash from combustion of forestry and agriculture biomass was a subject of study. Following physico-chemical properties have been determined:

- Size composition by use of laser analyzer Analysette 22 Fritsch
- Specific density by use of helium pycnometer
- Chemical composition by use of inductively coupled plasma atomic emission spectroscopy (ICP-AES) and inductively coupled plasma mass spectrometry (ICP-MS)
- Leachability of chemical pollutants was carried out in accordance with PN-EN 12457-2 [15]. Using ICP-AES and ICP-MS, pH and contamination were determined. Chloride contents was determined using titration method.

Then, in order to define the possible use of tested fly ash in suspension technologies, the ash-water suspensions were prepared by mixing ash with water in various weight ratios of water to ash (a/w). Suspensions with cement CEM II/ B-V 32,5 R addition were prepared. Properties of obtained suspensions were determined according to standard PN-G-11011:1998 "Materials for solidification backfill and mixtures to caulking gob. Requirements and test methods". [16]. According to above mentioned standard, the assessment of possibility of using fly ash in suspension technologies – in solidifying backfill and caulking gob - was conducted.

Results

Figure 1 shows the results of the particle size analysis of ash derived from biomass combustion in fluidized bed boiler. Grains of ash are slightly smaller than grains of fly ash from coal combustion. On the distribution curve characterizing particle size of tested ash, two peaks can be distinguished falling in the ranges of about 20 and 80 µm. Similarly situation is observed in case of coal ash, where two peaks falling in the ranges of about 30 and 110 µm are present, regardless of the type of furnace [17]. The largest grain size equaled 260µm, while grain content less than

Tab. 2 Characteristics of suspensions obtained from ash from biomass combustion

Tab. 2 Właściwości zawiesin sporządzonych z popiołu ze spalania biomasy

No.	Suspension composition [wt%]		Weight ratio of ash (solids) to water	Suspension density [Mg/m³]	Fluidity [mm]	Amount of supernatant water [%]	Setting time [h]	
	Fly ash	Cement					Start	End
1	100	0	1,1:1	1,45	180	5,0	120	240
2	100	0	1,0:1	1,38	210	5,2	144	312
3	100	0	0,9:1	1,34	230	8,6	216	384
4	100	0	0,8:1	1,33	250	10,2	216	420
5	100	0	0,7:1	1,28	280	12,7	288	504
6	90	10	1,1:1	1,45	185	5,3	50	148
7	80	20	1,1:1	1,44	190	5,6	42	88
8	70	30	1,1:1	1,43	200	5,8	30	42
9	90	10	0,7:1	1,28	280	13,9	122	320
10	80	20	0,7:1	1,28	285	14,1	63	223
11	70	30	0,7:1	1,25	310	17,2	53	151

0.1 mm was 87%.

Specific density of ash determined with use of helium pycnometer was 2.65 g/cm^3. Table 1 shows the results of the chemical pollutants leachability and pH determined in aqueous extract prepared from tested ash as well as limit values specified by PN-G-11011.

In studied samples of fly ash from agro-forestry biomass combustion there are no exceedances of limit values related to heavy metal content in the reflux water. The amount of sulfates was exceeded which was related to exhaust purification, and therefore presence of desulfurization products in fly ash. Sulfate content can be advantageous from the point of view of binding the barium ions that are present in mining waters. Chlorides contents also exceeds the limit value given in the standard. It should be noted that, according to standard [16], results obtained for leachability are used for calculation of actual total impurities discharged from the mine using suspension of tested ash. For comparison, Table 1 depicts results of chemical pollutants leachability from fly ash along with desulfurization products that was used in suspension technologies [10], despite the leachability of sulfate and chloride ions from ash in higher than that given in the standard.

Ash-water suspensions were prepared from fly ash derived from biomass combustion and they had ratios of ash to water (a/w) ranging between 0.7 and 1.1. In suspension where a/w equaled 0.7 and 1.1, fly ash was substituted with cement of 10, 20 and 30 wt%, while ratio of solids to water remained 0.7 and 1.1. This allowed to determine the effect of cement on properties of suspensions obtained in this way. For liquid suspensions, following parameters were determined: suspension density, Fluidity, supernatant water (separation water) and setting time. Then, suspensions were seasoned in air-dry conditions for 28 days, and after this period of time their uniaxial compression resistance Rc was determined as well as slakeability which was determined by immersion in water and observation of Rc. The results of suspension characteristics tests are presented in Table 2 and 3.

Tested suspensions demonstrated following properties:

- Suspension density – ranged between 1.25 and 1.45 Mg/m^3, which meets the requirements of standard that allows minimum density of 1.2 Mg/m^3
- Fluidity – suspensions demonstrated fluidity between 310 and 180 mm. At the same solids content in the water, addition of cement resulted in increase of fluidity from 5 to 30 mm. Fluidity of all prepared suspensions comforts standard PN-G-11011 requirements (minimum 180mm).
- The amount of supernatant water: ash-water suspension demonstrated amount of supernatant water from 5% (s/w = 1.1:1) to 12.7% (s/w = 0.7:1). Cement addition to suspensions of solids to water ratio (s/w) equal 1.1:1 slightly increased the amount of supernatant water do 5.8% (suspension having 30 % of cement content). In case of suspensions of s/w = 0.7, the amount of supernatant water increased to 17.2% for suspension containing 30% of cement. Except suspension containing 17.2% of supernatant water, all of the other met standard requirements of suspensions for gob caulking (maximum 15%), whereas requirements for solidifying backfill were met by suspensions of ratio a/w = 1.1:1 and 1:1 as well as by s/w = 1.1:1, regardless the amount of added cement.
- Setting time: for ash-water suspensions, setting time according to amount of ash ranged between 120 and 216 hours. Differences also occurred in starting stage of setting time, that took place from 120 to 288 hours from the moment of suspension preparation. Cement addition resulted in significant shortening of setting time of suspensions as well as accelerated start of their setting.
- Uniaxial compression resistance (Rc) – prepared

Tab. 3 Characteristics of suspensions prepared using ash from biomass combustion after 28 days of seasoning

Tab. 3 Właściwości zawiesin sporządzonych z popiołu ze spalania biomasy po 28 dniach sezonowania

No.	Suspension composition [wt%]		Weight ratio of ash (solids) to water	Uniaxial compression resistance after 28 days [MPa]	Slakeability [%]
	Fly ash	Cement			
1	100	0	1,1:1	0,31	60
2	100	0	1,0:1	0,12	62
3	100	0	0,9:1	0,04	64
4	100	0	0,8:1	0,04	62
5	100	0	0,7:1	0,03	75
6	90	10	1,1:1	0,31	60
7	80	20	1,1:1	0,55	56
8	70	30	1,1:1	0,61	41
9	90	10	0,7:1	0,07	65
10	80	20	0,7:1	0,12	46
11	70	30	0,7:1	0,12	48

ash-water suspensions demonstrated Rc from 0.03 MPa (a/w = 0.7:1) to 0.31 MPa (a/w = 1.1:1) after 28 days of seasoning in air-dry conditions. Cement applied to prepare suspensions favorably influenced on their Rc. In case of suspension of solids to water ratio (s/w) equal 1.1:1 and cement content of 20 and 30 wt%, uniaxial compression resistance was higher than that required for solidifying backfill (minimum 0.5 MPa).

- Slakeability – none of the tested samples have undergone this process, which fulfills requirements related to suspensions used for gob caulking. Slakeability of solidified suspensions ranged between 48% and 75% which, according to the standard [16], disqualifies these suspensions in terms of using them in solidifying backfill (maximum slakeability 20%).

Summary

Polish energy sector based primarily on the use of solid fuels for electricity and heat production purposes is waste producer that are mostly composed of fly ashes. In Poland, there are already boilers in power industry, that process biomass only and thus "new" wastes are produced – fly ashes from biomass combustion.

In order to determine the possibility of using fly ash from the biomass combustion in a fluidized bed boiler, its physico-chemical properties have been determined. The study was performed under the terms of using such ash in suspension technologies commonly applied in mining industry – solidifying backfill and gob caulking. Research carried out according to PN-G-11011 have shown, that obtained suspensions do not meet the requirements established for solidifying backfill, even when 30% of cement added. Almost all of the prepared suspensions can be applied in mines for gob caulking. The exception, due to exceeded limit of supernatant water, are suspensions of a/w = 0.7:1 and suspension s/w = 0.7 and 30% of cement content.

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Wykorzystanie popiołu lotnego z biomasy w technologiach zawiesinowych

W artykule przedstawiono wyniki badań dotyczących możliwości zastosowania popiołu lotnego ze spalania biomasy rolno-leśnej w kotle fluidalnym w technologiach zawiesinowych. W tym celu określono właściwości fizyko-chemiczne popiołu lotnego jak i właściwości zawiesin popiołowo-wodnych oraz zawiesin z dodatkiem cementu. Badano możliwości zastosowania zawiesin w podsadzce zestalanej oraz do doszczelniania zrobów.

Słowa kluczowe: biomasa, popioły lotne, technologie zawiesinowe, górnictwo