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Effects of biomass co-firing with coal on ash properties. Part I: Characterisation and PSD

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Abstract

The alterations of ash quality and utilisation aspects when co-firing coal with biomass were investigated. Co-combustion tests were performed in lab and semi-industrial scale facilities, using several coal–biomass blends. The collected ash samples were analysed for major elements and heavy metals content, loss on ignition (LOI), free CaO content and grain size distribution. Since a variety of co-combustion residues were tested, important implications concerning the ash composition and, consequently, its further use in potential applications came up. Results showed that properties of co-combustion residues are directly connected to the combustion conditions and the individual blend components. Biomass exploitation as secondary fuel in co-combustion processes is technically and economically feasible up to 20% w/w and the produced ash could be further utilised without any major treatment.

Keywords: Co-combustion residues; Analyses; Trace elements

1. Introduction

Disposal of ash coming from coal-fired power stations has caused significant economic and environmental problems. Several alternative uses of coal ash as a value-added product beyond its incorporation in construction materials were developed or are still under investigation, aiming to reduce ash disposal and its negative effects. Namely, fly ash is mostly used in the cement and concrete industry, while further applications for building materials, road works, binders, gypsum wallboards, mineral wool production, lightweight ceramics, metallurgy, waste water management, landfilling and agriculture have been reported [1–14]. The uses of fly ash define the significant parameters, i.e. physical, chemical and mineralogical properties, which should be determined. The related characterisation methods are mainly included in the standards governing the utilisation of fly ash, i.e. European norms, the analogous ASTM standards and additional national standards, i.e. British, Spanish and Canadian that are applicable to fly ash characterisation [15].

Apart from the national legislation, EN 450 "Fly ash for concrete" regulates the minimum requirements on fly ash, which is used as a component of concrete in many European countries. EN 450 Standard refers to ashes from coal combustion and within its revision residues from biomass and coal co-combustion will be also included. In this way, fly ash will be defined as a fine powder of mainly spherical, glassy particles, derived from burning of pulverised coal, with or without co-combustion materials. Possible

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co-combustion materials are vegetable material like wood chips, straw, olive shells and other vegetable fibres, green wood and cultivated biomass, animal meal, municipal sewage sludge, paper sludge, petroleum coke and virtual ash free liquid and gaseous fuels. The fly ash from co-combustion should be obtained from a mixture of pulverised coal and co-combustion materials, where the minimum percentage, by dry mass, of coal is greater than 80% and where the maximum proportion of ash derived from co-combustion material does not exceed 10%. It is expected that this revision in EN450 will seriously influence the European situation of fly ash utilisation.

The aim of this paper is to present the properties of different co-combustion residues with respect to their potential uses and legislative restrictions. The ash samples of several coal/biomass blends were produced in lab and semi-industrial scale facilities and were subject to ash characterisation methods. Specifications concerning the composition of co-combustion residues were accrued based on the analysis results. Since a variety of co-combustion ashes were investigated, it is expected that the indications provided to the potential users of this type of residues will be proved valuable for future applications.

2. Methodology

2.1. Fuel blends formation and ash production

Biomass samples, characteristic of the Greek region were used to produce ashes in the test facilities. Biomass resources in Greece constitute mainly of residues resulting from agricultural and agro-industrial activities. Olive kernel is a representative sample of such residues that is used for energy production purposes. Furthermore, the extensive use of wood and wood-based products results in high quantities of waste wood and wood residues. Therefore, the secondary fuels that were examined are olive kernel and wood. The latter were tested in conjunction with Greek lignite from the Ptolemais reserve, which represents almost 33% of total Greek lignite remaining quantities. Co-combustion residues were initially produced in an electric muffle furnace. The fuel alone or the lignite/biomass blend was pulverised in less than 250 mm, mixed thoroughly, weighed and heated gradually, up to 450–500 °C in the first hour. Subsequently, the sample temperature reached 700–750 °C in the second hour. Ashing was continued at this temperature for two additional hours. In case of the pure biomass sample, temperature did not exceed 575 °C. The sample was then removed from the muffle, cooled, weighed and characterised. An extensive series of experiments were realised in a 0.75 MW_{th} hot water boiler, in which fly and bottom ash samples were collected. Similar secondary fuels as in the lab-scale tests, consisting of forest residue and olive kernel were used in the preparation of the blends with coal. The addition of biomass species was up to 20% w/w, even when both secondary fuels were burnt in conjunction with lignite.

Table 1
Proximate, ultimate and ash analyses of Greek lignite and secondary raw materials

	Lignite	Pine wood	Oak wood	Olive kernel
Proximate analysis, % w/w (as received)				
Moisture	53.8	28.20	23.55	13.50
Volatiles	23.24	67.49	66.89	61.10
Fixed carbon	10.58	3.70	8.94	16.70
Ash	12.38	0.61	0.60	8.70
Ultimate analysis, % w/w (dry basis)				
C	43.19	39.58	38.95	40.53
H	4.09	5.17	4.97	4.70
N	1.43	0.08	0.11	2.79
S	1.33	0.19	0.04	0.50
O[a]	23.16	54.13	55.13	41.38
Ash	26.80	0.85	0.80	10.10
Ash analysis, % w/w				
SiO_2	32.65	14.45	16.21	45.05
Al_2O_3	17.27	2.71	2.37	6.98
Fe_2O_3	8.74	1.61	0.54	6.24
CaO	21.24	51.3	46.24	22.90
MgO	5.28	8.00	7.11	3.77
SO_3	6.00	–	–	1.57
Na_2O	0.3	0.17	0.24	0.93
K_2O	0.8	10.04	18.62	9.18
P_2O_5	0.30	2.82	4.02	2.36
Rest	7.42	8.90	4.64	1.01

[a] By subtraction.

2.2. Fuels and ash characterisation

ASTM methods were applied for the determination of primary properties of the solid materials. Typical analyses of the fuels are given in Table 1. Characterisation of ash samples coming from the co-combustion experiments was carried out aiming to investigate the potential of exploiting these residues in construction works. Sulphur trioxide, moisture, carbon content (loss on ignition), total oxides, magnesium oxide, morphology, pozzolanic activity and fineness are the most important characteristics to be examined during the fly ash utilisation in the cement and concrete production processes. An ICP-AES spectrophotometer was employed for the analysis of heavy metals, since some of them are of environmental concern. The determination of the major elements and heavy metals was carried out both for the ash samples produced laboratory and collected at the boiler. Furthermore, the loss on ignition (LOI), the free CaO content and the grain size distribution were measured in each collected ash sample.

3. Results and discussion

3.1. Ash characterisation

3.1.1. Main components in fuel ash

Ash chemical analyses of Ptolemais lignite, two wood species and olive kernel are presented in Table 1. The content of CaO in wood ash is higher compared to the lignite ash, exceeding 50 (% w/w) in pine wood. A high content