JOURNAL OF ENVIRONMENTAL SCIENCES XX (2016) XXX–XXX

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Chemical composition and properties of ashes from combustion plants using *Miscanthus* as fuel

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ARTICLE INFO

Article history:
Received 5 November 2015
Revised 2 March 2016
Accepted 15 March 2016
Available online xxxx

Keywords:
Biomass combustion
Miscanthus
Ash composition
Ash properties

ABSTRACT

Miscanthus giganteus is one of the energy crops considered to show potential for a substantial contribution to sustainable energy production. In the literature there is little data available about the chemical composition of ashes from the combustion of *Miscanthus* and practically no data about their physical properties. However, for handling, treatment and utilization of the ashes this information is important. In this study ashes from two biomass combustion plants using *Miscanthus* as fuel were investigated. The density of the ashes was 2230 ± 35 kg/m^3, which was similar to the density of ashes from straw combustion. Also the bulk densities were close to those reported for straw ashes. The flowability of the ashes was a little worse than the flowability of ashes from wood combustion. The measured heavy metal concentrations were below the usual limits for utilization of the ashes as soil conditioner. The concentrations in the bottom ash were similar to those reported for ash from forest residue combustion plants. In comparison with cyclone fly ashes from forest residue combustion the measured heavy metal concentrations in the cyclone fly ash were considerably lower. Cl^-, S and Zn were enriched in the cyclone fly ash which is also known for ashes from wood combustion. In comparison with literature data obtained from *Miscanthus* plant material the concentrations of K, Cl^- and S were lower. This can be attributed to the fact that the finest fly ash is not collected by the cyclone de-dusting system of the *Miscanthus* combustion plants.

Introduction

Concerns about climate change caused by the carbon dioxide emissions from the combustion of fossil fuels lead to a continuous rise in the combustion of biomass for heat and power generation (European Biomass Association, 2013). The combustion of biomass is considered to be almost carbon dioxide neutral because the carbon dioxide emissions produced during the combustion process are almost offset by the carbon dioxide fixed by photosynthesis during the growth of the biomass. Besides forest and agricultural residues energy crops are also used as fuels in biomass combustion plants. *Miscanthus giganteus* is one of the energy crops being considered to show the potential for a substantial contribution to sustainable energy production (Lewandowski et al., 2003). In Europe the area of agricultural land where *Miscanthus* was grown in 2011 was approximately 20,000 ha (European Biomass Association, 2013). In 2014, the acreage of *Miscanthus* in Austria was 1180 ha (Statistik Austria, 2015) with the main production areas being in Upper and Lower Austria. The yield of dry biomass depends on the soil quality, the water supply and the temperature. In upper Austria, the yield on good soil is in the range of 15–22 ton dry mass per hectare (Frühwirth and Liebhard, 2006).

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http://dx.doi.org/10.1016/j.jes.2016.03.032
1001-0742/

Please cite this article as: Lanzerstorfer, C., Chemical composition and properties of ashes from combustion plants using *Miscanthus* as fuel, J. Environ. Sci. (2016), http://dx.doi.org/10.1016/j.jes.2016.03.032

In the combustion of *Miscanthus* the inorganic constituents remain as ash. Most of the ash is discharged as bottom ash but some of the ash leaves the combustion zone together with the off-gas as fly ash. The amount of produced fly ash depends on the combustion conditions and the type of combustion process. In biomass combustion the fly ash typically accounts for about one quarter of the total amount of ash (van Loo and Koppejan, 2008). In smaller size combustion plants the fly ash is collected in a single de-dusting stage by a cyclone or a multi-cyclone. The collected cyclone fly ash is usually discharged from the combustion process together with the bottom ash as mixed ash. The total ash content of *Miscanthus* is reported to be in the range of 2.0%–3.5% (European Biomass Association, 2013). Similar values were reported by Baxter et al. (2012) and Michel et al. (2012) for the ash content of samples from the whole plant.

In many countries ashes from the combustion of chemically untreated biomass are utilized as soil conditioner on agricultural land and forests if the concentrations of pollutants are below the limit relevant concentrations. The recycling of biomass ashes to the soil is proposed to help to close the nutrient cycles for the soil where the biomass was grown (von Wilpert et al., 2014). Country-specific limit concentrations for heavy metals can be found in the literature (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2011; Emilsson, 2006; Nurmesniemi et al., 2012).

The ashes from the combustion processes are bulk materials that have to be handled, stored, treated and utilized or disposed of at landfill sites. The chemical composition of ashes is essential in determining its utilization. For its use as a soil conditioner the country-specific limits are decisive. The physical ash properties like the bulk density and the flowability are important parameters for the design of the handling and storage facilities (Schulze, 2008).

In the literature there is only little data available for the chemical composition of ashes from the combustion of *Miscanthus*. Baxter et al. (2012) and Michel et al. (2012) reported the concentrations of main ash components in ashes produced by combustion of small samples of *Miscanthus* in a muffle furnace at 550°C for 3 hr and 400°C for 8 hr, respectively. The ash content and concentration data for main ash components and some heavy metals for *Miscanthus* plants are available in Obernberger et al. (2006). From this data the expected content of the components in the ash can be calculated. No data was found in the literature for the physical properties of ashes from the combustion of *Miscanthus*.

The aim of this study was to characterize bottom ash and cyclone fly ash from the combustion of *Miscanthus* in full scale combustion plants with respect to their chemical composition and their physical properties.

1. Materials and methods

1.1. Material

The ashes investigated in this study were collected from two grate-fired biomass combustion plants using *M. giganteus* as fuel. The thermal capacity of plant A and plant B was 400 KW_{th} and 750 KW_{th}, respectively. The biomass for the two combustion plants was grown in Lower Austria (250 m a.s.l.) and Upper Austria (350 m a.s.l.), respectively. In April, the culm material was harvested leaving the leaves out on the soil. The material was chopped and stored under open air roof. In both plants the combustion temperature measured about 1 m above the combustion grate was approximately 600°C. Each plant was equipped with a cyclone for the de-dusting of the combustion off-gas. Ash samples of 1 dm^3 were collected at the ash discharge systems. From plant A only a combined bottom ash and cyclone fly ash sample could be obtained, whereas, in plant B the bottom ash and the cyclone fly ash were collected separately. The volume of the ash samples was reduced to a volume suitable for the various laboratory tests using sample dividers which were applied repeatedly (Haver&Boecker HAVER RT and Quantachrome Micro Riffler).

1.2. Analytical methods

The moisture content of the dust samples was determined with an OHAUS, type MB 45 moisture analyser. The dust samples were dried at 105°C until the weight of the sample was constant. The particle size distribution of the ash samples was determined using a Fritsch ANALYSETTE 3 PRO laboratory sieve shaker with sieves from 10 to 500 μm. The undersize material of the 500 μm sieve was analysed using a Sympatec, type HELOS/RODOS laser diffraction instrument with dry sample dispersion. The calibration of the instrument was verified with a SiC-P600'06 standard from Sympatec. The target value for the mass median diameter x_{50} is 25.59 μm and the acceptable range is 24.82 to 26.36 μm. The measured value for the x_{50} was 25.64 μm.

The density of the ashes ρ_S (particle density) was determined according to EN ISO 8130-3 (European Committee for Standardization, 2011). The mass and the volume of a test portion of ash were determined using a 100 cm^3 liquid displacement pyknometer. N-heptane (density: 0.681 g/cm^3) was used for the displacement of the air. The bulk density ρ_B of the ash samples was determined according to EN ISO 60 (European Committee for Standardization, 1999). For the measurement 120 cm^3 of the powder stored in a funnel flow by gravity into the coaxial 100 cm^3 measuring cylinder. The volume of the certified measuring cylinder is 100 ± 0.5 cm^3 and the precision of the balance was ±0.01 g. The excess material is removed by drawing a straight blade across the top of the cylinder. The voidage was calculated as $1 - \rho_B / \rho_S$.

The angle of repose can be used as a flowability indicator for bulk solids and powders. It was measured according to ISO 4324 (International Organization for Standardization, 1977). For the measurement a cone of material is obtained by passing the powder through a special funnel placed at a fixed height above a completely flat and level circular plate. The base angle of the cone is calculated from the diameter of the base plate and the height of the cone. The reproducibility of the measurements was ±1°.

The yield locus for the ash samples was determined using a Schulze RST-XS ring shear tester with a 30 cm^3 shear cell. The test procedure was conducted in accordance with ASTM D 6773 (2008) at four values of the normal stress (600, 2000, 6000 and 20,000 Pa). A quantitative characterization of the

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