Available online at www.sciencedirect.com

ScienceDirect

www.journals.elsevier.com/journal-of-environmental-sciences

JOURNAL OF ENVIRONMENTAL SCIENCES
www.jesc.ac.cn

Chemical composition and physical properties of filter fly ashes from eight grate-fired biomass combustion plants

Christof Lanzerstorfer

School of Engineering and Environmental Sciences, University of Applied Sciences Upper Austria, Stelzhamerstraße 23, A-4600 Wels Austria

ARTICLE INFO

Article history:
Received 9 May 2014
Revised 7 July 2014
Accepted 1 August 2014
Available online 31 January 2015

Keywords:
Biomass combustion
Filter fly ash
Chemical analysis
Physical properties

ABSTRACT

For the handling, treatment and utilization of fly ash from biomass combustion its chemical composition and physical properties are important. In this study eight filter fly ashes from different grate-fired biomass combustion plants were investigated. In fly ash from straw combustion high concentrations of (K) were found, whereas in the fly ash from wood combustion the concentrations of Ca and Mg were higher. The average concentration of PO_4^{3-} was similar in both types of fly ashes. In all wood fly ashes some measured heavy metal concentrations were above the limits for utilization. The straw fly ashes were much less contaminated and can be utilized. For wood fly ash most parameters showed little variation, except from one fly ash where the dust pre-separator is in poor condition. The average values were: mass median diameter 4.3±0.8 μm, spread of particle size distribution 19±11, particle density 2620±80 kg/m^3 and angle of repose 50°±1°. The density of the straw fly ashes is lower (2260±80 kg/m^3) and the spread of the size distribution is higher (72±24). For one straw combustion fly ash the values of the mass median diameter and the angle of repose were similar to the values of wood combustion fly ash, for the other straw fly ash the values differed considerably. While the particle size of this fly ash was much smaller, surprisingly the angle of repose was also lower. This can be attributed to the formation of small agglomerates in this fly ash, which were not disintegrated without a certain stress.

Introduction

Due to the limited availability of fossil fuels and concerns about climate change caused by the carbon dioxide emissions from fossil fuel combustion, the combustion of biomass for heat and power generation is rising continuously (European Biomass Association, 2013). The combustion of biomass is considered to be nearly carbon dioxide neutral because the carbon dioxide emissions produced during combustion are almost compensated by the carbon dioxide fixed in the biomass while it grows.

In the combustion process the inorganic constituents of the biomass remain as ash. The finer ash particles leave the combustion zone together with the off-gas as fly ash. Before the discharge of the off-gas the fly ash has to be separated. In order to comply with low dust emission limits at standard pressure and temperature (STP) (<20 mg/m^3 (STP)), a fabric filter or an electrostatic precipitator (EP) has to be used for the separation of the fly ash. Upstream of these separators a pre-separator, *e.g.*, a cyclone is usually installed. If the coarser dust is collected in a pre-separator the filter fly ash accounts for 2%-10% of the total amount of ash (Narodoslawsky and Obernberger, 1996).

The filter fly ash is a bulk material with a small grain size that has to be handled, treated and utilized or disposed of at landfill sites. For the decision about the further fate of the fly ash the chemical composition is essential. The physical properties are relevant for the design of the handling and storage facilities.

In Austria only bottom ash and cyclone fly ash from the combustion of chemically untreated biomass can be utilized as a

E-mail address: c.lanzerstorfer@fh-wels.at.

http://dx.doi.org/10.1016/j.jes.2014.08.021

soil conditioner on agricultural land and forests if the concentrations of pollutants are below the limit concentrations (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2011). Filter fly ash is not allowed to be used in that way because the concentrations of volatile heavy metals are highest in this fine ash fraction. Therefore, excluding the filter fly ash from recirculation to the soil where the biomass has grown provides a sink for these elements. In other European countries the conditions for biomass fly ash utilization are different. The limit concentrations for some Scandinavian countries and Lithuania are summarized in Table 1.

For the design of the storage bins and other ash handling equipment physical properties of the fly ash like the bulk density and the angle of repose are important. The angle of repose can also be used for an approximate categorization of the flowability of the material.

In the literature some data are available for the chemical composition of biomass filter fly ashes. In several studies (Dahl et al., 2009; Singh et al., 2011; Melotti et al., 2013; Sano et al., 2013) data of fly ashes from the combustion of woody biomass and mustard stalks collected in EPs have been reported. As there was no pre-separator installed in the combustion plants where the samples were collected, the particle size distribution of the investigated fly ash samples was rather coarse. In two of these studies the mass median diameter of the fly ash is reported to be 100 and 60 μm. Some data of second stage filter fly ash are available in van Loo and Koppejan (2008). Sander and Andrén (1997), Hansen et al. (2001) and Aguiar del Toro et al. (2009) reported on the chemical composition of fly ash from straw combustion. However, no information is given on the type and arrangement of dust separators where the fly ash samples were collected. Generally, one can say that in the published studies, the type and number of the analyzed components vary a lot and that in no work the broad spectrum of components from the nutrients to the heavy metals is covered.

Data on the physical properties of fly ash from biomass combustion are very rare. In van Loo and Koppejan (2008) data for the density and the bulk density of filter fly ashes are reported.

The aim of this study was to characterize filter fly ashes from the combustion of wood and straw with respect to their chemical composition and their physical properties. It was particularly intended to provide a complete set of physical properties and chemical composition data for each fly ash sample because the published literature usually focuses only on certain parameters of the samples investigated. All fly ashes from the combustion of woody biomass were taken from the second stage of two-stage dust separation systems. Of the fly ash samples from straw combustion plants, only one is from a plant where a pre-separator is installed, the other is from the off-gas filter of a single-stage system.

Table 1 – Heavy metal concentration limits for utilization of ash from biomass combustion as a soil conditioner in forests and agriculture (unit: mg/kg dw).

	Finland [a]	Sweden [b]	Lithuania [c]
As	40	30	30
B		500	500
Cd	25	30	30
Cr	300	100	100
Cu	700	400	400
Hg	1.0	3	3
Ni	150	70	70
Pb	150	300	300
V		70	70
Zn	4500	7000	700

dw: dry weight.
[a] Data source is from Nurmesniemi et al., 2012.
[b] Data source is from Emilsson, 2006.
[c] Data source is from Stupak et al., 2008.

1. Materials and methods

1.1. Material

Fly ash from eight grate-fired biomass combustion plants was collected for this study. The samples were taken from the dust discharge of the final dedusting system which was either an electrostatic precipitator (EP) or a fabric filter. An overview of the thermal capacities of the combustion plants, the type of dust separator installed and the combusted biomass is given in Table 2. In all plants for the combustion of woody biomass (from plant A to plant F) a pre-separator, usually a cyclone, is installed upstream of the final dust separator from which the samples were taken. The arrangement is the same in plant G, whereas in plant H no pre-separator is installed upstream of the dust filter. In plant F some hydrated lime is added to the off-gas before it enters the separator. The volume of each fly ash sample of approximately 2 dm^3 was collected. The sample volumes were reduced to a volume suitable for the various laboratory tests using sample dividers which were applied repeatedly (Retsch PT100, Quantachrome Micro Riffler).

1.2. Chemical analysis

All chemical analyses of the fly ashes were measured in duplicate. In the results the average values are presented. The moisture content was measured gravimetrically. The samples were dried at 105°C for 1 hr. The carbon content (TC) was determined with a LiquiTOC system from Elementar Analysensysteme, Hanau, Germany. By combustion with air the carbon is transformed into CO_2 which is subsequently analyzed.

The solid fly ash samples were dissolved by aqua regia digestion (International Organization for Standardization, 1995) prior to analysis of the concentration of metals, sulfate and phosphate. The concentration of most metals was measured by inductively coupled plasma optical emission spectroscopy (ICP-OES) using an Ultima 2 from Horiba Jobin Yvon, Bensheim, Germany. The concentration of mercury was measured using cold vapor atomic absorption spectrometry (CV-AAS) according to EN ISO 12846 (European Committee for Standardization, 2012). The concentration of alkali and earth alkali metals, sulfate and phosphate was measured by ion chromatography (IC) using a Dionex (Sunnyvale, Carlifornia, USA) ICS-1000 system. For analysis of cations the set-up was: analytical column IonPac® CS12A 4 × 250 mm; suppressor: CSRS® 300, 4 mm; eluent: 20 mmol methanesulfonic acid, flow rate 1.0 mL/min. For the measurements of anions the set-up was: analytical column IonPac® AS14A 4 × 250 mm; suppressor: ASRS® 300, 4 mm; eluent: 8.0 mmol sodium carbonate/1.0 mmol sodium hydrogen carbonate; flow rate 1.0 mL/min.

The chloride and nitrate concentration of a solid sample cannot be analyzed after digestion by aqua regia. As nearly all chlorides and nitrates are highly soluble in water, the concentration of chloride and nitrate of a sample can be