Fuel 180 (2016) 606–612

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Biomass composition and ash melting behaviour of selected miscanthus genotypes in Southern Germany

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HIGHLIGHTS

- Contents of ash, K and Cl are good indicators of biomass combustion quality.
- Optimization of biomass composition through crop management strategies can be a good tool to improve the ash melting behaviour.
- Sintering tendencies were lower for the thin stemmed *M. sinensis* genotypes than for all other genotypes.

ARTICLE INFO

Article history:
Received 6 July 2015
Received in revised form 13 April 2016
Accepted 19 April 2016
Available online 26 April 2016

Keywords:
Miscanthus
Combustion
Ash melting
Ash
Potassium
Chloride

ABSTRACT

Optimization of biomass composition can lead to reduction of both ash-related problems such as slagging, fouling and corrosion as well as emissions (NO_x, SO_x) when combusted. This study aims to monitor the ash melting behaviour of biomass over a period of eight years from 15 miscanthus genotypes grown at Ihinger Hof research station, near Stuttgart, Germany and explain the relationship between biomass composition and ash melting behaviour. To do this, biomass ash samples were prepared and subjected to different heating treatments (800–1100 °C) and categorized into 4 ash-fusion classes based on microscopic observations. The outcome of the study reveals that the sintering tendencies were lower for the *Miscanthus sinensis* genotypes than for all other genotypes but these genotypes are low yielding. Furthermore, *M. sinensis* hybrids and *Miscanthus sacchariflorus* performed better than *Miscanthus* × *giganteus* genotypes at higher temperatures. The correlation analysis between biomass composition and ash melting behaviour suggests that ash, K and Cl contents play a key role in inducing ash-related problems.

1. Introduction

The depletion of fossil fuels together with their atmospheric carbon footprint and global climate change necessitate the use of sustainable energy resources. Lignocellulosic biomass such as crop residues, dedicated energy crops have the potential to deliver bioenergy without any direct competition with food [1]. Therefore, such feedstocks can be used to supply alternative fuels for heat and electricity generation through combustion or for the production of 2nd generation ethanol and biogas. In Europe, the rhizomatous C4 grass miscanthus has emerged as a strong candidate for biomass-based energy production due to its potential to deliver high biomass yields under low input conditions. In addition, the long-term productivity of the perennial crop miscanthus makes it one of the preferred choices among energy crops mainly because soil carbon is stored and nutrients are recycled efficiently within the plant system [2]. According to the statistics from the years 2006–2008, the cultivation area for miscanthus in Europe is 38,300 ha [3]. This is already more than the 35,018 ha under short rotation coppice (willow, poplar) [3]. Miscanthus is mainly used to provide solid fuel to power plants with many smaller-scale areas supplying biomass for domestic heating plants.

Various miscanthus genotypes have been tested in Europe to select those best suited for biomass production in terms of yield [4,5] and fuel quality [2]. Currently, power is mainly produced from miscanthus through direct combustion of its biomass. However, the efficiency of this power generation depends on the composition of the solid fuel being combusted. During the bioconversion processes, high moisture content of the harvested biomass leads to higher energy input for drying prior to combustion and low heating value. Similarly, high ash content and/or low ash-fusion temperature pose technical issues through deposition, sintering, fouling, slagging and corrosion. The latter can damage

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http://dx.doi.org/10.1016/j.fuel.2016.04.073
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boilers and increase maintenance costs. The ash-forming elements potassium (K), phosphorus (P), chloride (Cl), silicon (Si), calcium (Ca) and sulphur (S) contribute to the above-mentioned ash-related mechanical problems. The main quality problems caused by combustion of poor quality biomass include:

- corrosion and fouling (K, Cl, ash)
- low ash melting point (K, S, Cl, Si)
- emissions (N, S)

The content of Ca and Mg has positive effect on ash melting behaviour. Any increase in Ca and Mg content will lead to improved ash melting behaviour [15].

To evaluate the effect of chemical composition of biomass, several indices have been developed to estimate the rate of fouling and slagging in biomass-based combustion. However, the most widely used are alkali indices and an ash composition index [6]. These indices provide useful information to describe the relationship between fuel composition and ash melting behaviour. The value of alkali index higher than one is an indication of increased fouling rate during the combustion process [7].

The importance of alkali index as an indicator of fouling rate signifies that K and Na contents are highly critical. This is mainly due to their tendency to react at relatively low temperature during the combustion process [8].

As Na content is very low in miscanthus biomass, K is of main relevance in ash melting behaviour. At elevated temperatures, biomass with high K, Cl, Si and S contents lead to formation of low-fusion-temperature silicates and sulphates, which decrease the efficiency of the thermal bioconversion mechanism through bed sintering and deposition on heater tubes [7,9]. Therefore, for biomass-based energy production to be economical and environmentally benign, it is important to address the above-mentioned mechanical problems. There are various possibilities for improving the efficiency of power plants. These include ensuring the supply of good quality biomass over the years through different crop management practices such as selection of appropriate genotypes. Apart from crop management practices technical upgrading of boilers could also help to counter the combustion related problems.

Through the appropriate combination of management practices, the composition of solid fuel – especially alkali metal and chloride contents – can be optimized. For example, leaching of minerals especially Cl by rain [10], appropriate harvesting time and fertilization application can all contribute significantly towards improvement of ash melting behaviour [11]. However, in current study, the focus is mainly on selection of genotypes with the potential to deliver high biomass quality for combustion over the years. It is important to state that technical upgrading of power plants does not fall into the remit of this study. This paper aims to monitor the ash melting behaviour of the biomass from selected miscanthus genotypes over the years and identify the factors responsible. As the data about biomass composition is already published, therefore in current study the effect of biomass composition on ash melting behaviour will only be evaluated.

Biomass samples from 15 miscanthus genotypes harvested in the years 2004–2011 were subjected to mineral analysis, which is already published [2]. Based on published information about dry matter yield and biomass composition, ash melting behaviour was performed for all genotypes for selected years (2004, 2008 and 2011) and selected genotypes for all years (2004–2011). Biomass ash samples from each genotype were prepared at low temperature (550 °C) and then heated to temperatures between 800 and 1100 °C to monitor the ash melting behaviour, the ash samples were then categorized by microscopic analysis into 4 ash-fusion classes [10]. The data was collected and analysed by following Proc Mixed procedure. In addition, correlation analysis was performed between biomass composition and ash melting behaviour.

2. Material and methods

2.1. Biomass samples

The miscanthus biomass samples used in this experiment were collected from a field trial established in 1997 under the European Miscanthus Improvement (EMI) project at Ihinger Hof (48°40′N: 09°00′E) in south Germany. The 15 miscanthus genotypes planted in this project are: 4 *Miscanthus* × *giganteus* (Gig), 1 *Miscanthus sacchariflorus* (Sac), 5 *Miscanthus sinensis* (Sin) and 5 *M. sinensis* hybrids (Sin-H). During the years 2004–2011, N fertilization was applied at the rate of 60 kg N ha^{-1} a^{-1} (NH_4NO_3), P 50 kg ha^{-1} a^{-1} (P_2O_5), K (K_2SO_4) at the rate of 144 kg ha^{-1} a^{-1}. It is important to state that in practice, fertilization is not common but in this field trial nutrient fertilization was carried out because the aim of this field trial was to assess the yield potential and long term productivity of different miscanthus genotypes. The fertilization recommendations were made based on the nutrient removal rate through harvested biomass.

The soil pH ranged from 7.2 to 7.7. The N content of soil decreased along the soil profile from 0.20% (30 cm) to 0.04% (90 cm), P content decreased from 14.1 mg/100 g (30 cm) to 1.3 mg/100 g (90 cm) and K content decreased from 31.3 mg/100 g (30 cm) to 1.3 mg/100 g (90 cm). For further details on genotypes and field trial performance see [2].

Biomass samples were collected from an area of 0.5–1.5 m^2 each year (harvest within the period January to April) using manual cutters. The harvesting time (from early to late harvest) was varied with the aim to assess the response of different genotypes to different harvesting times in terms of yield and quality. Samples were dried, chopped, ground and then passed through a 1-mm sieve. The samples were used for mineral analysis [2] and preparation of ash samples to monitor ash melting behaviour. Based on dry matter yield and biomass composition analysis information [2], for current study biomass samples from the years 2004 to 2011 were divided into two groups. In the first group, all 15 genotypes were analysed for 3 selected years (2004, 2008 and 2011). Years were selected based on considerable annual variation in terms of dry matter yield and biomass composition. In the second group, the most promising genotypes (Gig-2, Sac-5, Sin-H7 and Sin-13) in terms of dry matter yield and with contrasting biomass quality (based on already published data [2] were selected for ash melting behaviour for all years (2004–2011). The sample handling, preparation and heating treatments were identical for both groups.

2.2. Laboratory analysis

Dried biomass samples were analysed in the laboratory for mineral (N, P, K, Na, Cl, Si, Ca, Mg) and ash content. The analysis methods are listed in Table 1.

2.3. Heating of the ash samples

Low-temperature ash samples were prepared by heating 10-g biomass samples in ceramic crucibles in an electric muffle furnace at 550 °C for 4 h. From each low-temperature ash sample approximately 100 mg was transferred to a separate ceramic combustion boat. These were placed in an electric muffle furnace, which was heated at an average rate of 10 °C min^{-1} until the required heating temperature was achieved. All the low-temperature ash samples were subjected to 4 different temperature treatments of 800 °C, 900 °C, 1000 °C and 1100 °C. After two hours, the combustion boats