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Biosystems ENGINEERING

Research Paper

Use of electrostatic precipitators in small-scale biomass furnaces to reduce particulate emissions from a range of feedstocks

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A R T I C L E   I N F O

Article history:
Received 9 February 2017
Received in revised form
27 August 2017
Accepted 31 August 2017

Keywords:
Electrostatic precipitators
Biomass combustion
Particulate emissions

The results of a study into the precipitation efficiencies of two different electrostatic precipitator (ESP) types (chimney top with manual cleaning and in-line with automated cleaning) using three biomass fuels with low (wood), medium (willow) and high (tall fescue) particulate emission levels are presented. Testing showed that precipitation efficiencies of greater than 70% are possible in an inline system with automated cleaning, while in the chimney top, manual cleaning system high efficiencies can be achieved for willow (86%) and wood (69%) on a short term basis. For low emission fuels such as wood (<10 mg Nm^{-3}), acceptable precipitation efficiencies (~70%) could be achieved and maintained over a long time period on both automated and manual systems. For medium (willow > 100 mg Nm^{-3}) and high (tall fescue > 300 mg Nm^{-3}) emission fuels it was found that the use of an automated cleaning system is necessary to maintain precipitation efficiencies at acceptable levels. In the chimney top type, system efficiencies dropped to zero with willow after 50 h and with tall fescue after 10 h of combustion with no cleaning, due to build-up of particulate matter on the electrode causing reduced distribution of charge to the oncoming particles. For the in-line system, it was also shown that an improved electrode design had the capacity to increase precipitation efficiency by on average 18%. It was concluded that ESPs have an important role to play in particulate emission reduction in future low emission biomass combustion systems if they are to meet stricter particulate control guidelines.

1. Introduction

Global interest in renewable energy has grown over the last decade driven by fuel security concerns as well as by efforts to mitigate the effects of climate change (Solomon et al., 2007; Worldwatch Institute, 2006). Interest in renewable energy has solidified into binding targets such as the European Union's target to achieve 20% of renewable energy by 2020 (Directive 2009/28/EC). Combustion is the most mature technology for biomass utilisation (Nussbaumer, 2003). The primary feedstock for biomass combustion is wood but

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http://dx.doi.org/10.1016/j.biosystemseng.2017.08.021
1537-5110/

feedstocks such as straw, energy crops and herbaceous fuels are also suitable for combustion (Nussbaumer, 2003; Obernberger, Brunner, & Barnthaler, 2006). Given the fact that wood supplies are limited, at least in some countries, alternative feedstocks are likely to be a major component in the future energy feedstock mix. Smith, Powlson, Smith, Fallon, and Coleman (2000) stated that energy crops are likely to be major contributors to the renewable energy mix in the future and have been shown to have great potential to mitigate carbon emissions.

Although biomass combustion can make a significant contribution to renewable energy generation, emissions from biomass combustion are typically greater in comparison to the combustion of natural gas or light fuel oil and can contribute significantly to concentrations of particulate matter, ozone and nitrogen dioxide in ambient air (Nussbaumer, 2003). Particle emissions from biomass combustion primarily result from the release of inorganic material from the fuel, such particles consist mainly of K, Cl, S, Na although the principal element is K (Nussbaumer, 2003; Obernberger et al., 2006). Thus, particulate emissions from the combustion of biomass can be expected to be directly related to the quantity of inorganic material (i.e. ash) in the fuel. Fuels such as straw and herbaceous materials have been shown to have significantly greater quantities of ash compared to wood (Carroll & Finnan, 2012); particulate emissions from such fuels have been demonstrated to be considerably higher than particulate emissions from wood (Verma, Bram, Gauthier & De Ruyck 2011a,b). A relationship between air pollution and mortality has been demonstrated in the United States (Dockery et al., 1993). It has been demonstrated that long term exposure to combustion related fine particulate matter is a major risk factor associated with cardiopulmonary diseases and lung cancer mortality (Pope et al., 2002). In Europe, high ambient levels of particulate matter have an impact on a sizable proportion of the European population particularly in urban areas (EEA, 2012).

There is increasing concern over the level of particulate emissions from biomass combustion; the contribution of biomass combustion to particulate emissions from the residential sector exceeds 80% in some countries (Obernberger & Mandl, 2011). Concern over particulate emissions from biomass combustion has led to stricter regulations in some European countries such as Switzerland and Germany (Obernberger & Mandl, 2011). Additionally, the expansion of the EU Ecodesign directive (2009/125/EC) to include biomass combustion devices will introduce stricter limits on particulate emissions from biomass combustion (Smit, 2011). Particulate emissions may be reduced by altering the chemical composition of the feedstock through the use of additives or fuel blending (Bäfver, Rönnbäck, Leckner, Claesson, & Tullin, 2009; Fagerström, Nyström, Boström, Öhman & Boman, 2010). Alternatively, particulate emissions from biomass combustion can be reduced by the use of secondary measures such as filters and electrostatic precipitators (Van Loo & Koppejan, 2008). Particles larger than 5 μm can be effectively removed by cyclone separators but effective removal of particles smaller than 1 μm requires the use of electrostatic precipitators or baghouse filters (Obernberger et al., 2006). Until recently, such secondary measures were only considered economical for medium and large scale installations (Obernberger et al., 2006). However, concern over particulate emissions from small scale biomass combustion units and stricter regulations have precipitated the development of a large number of electrostatic precipitators suitable for small scale units. Bologa, Paur, Seifert, Woletz, and Ulbricht (2011a) have described electrostatic precipitators as effective devices for small particle control in small scale combustion devices. Obernberger and Mandl (2011) conducted a survey of particle precipitation devices suitable for biomass combustion devices up to a capacity of 50 kW and concluded that electrostatic precipitators were the most promising technological approach to particle emissions reduction in small scale applications. Thirteen electrostatic precipitators were included in the study and a large number of additional designs are expected to be released onto the market over the next number of years. Nussbaumer and Lauber (2010) found that ESP devices were particularly effective for the removal of the salt component of particulate matter.

Laitinen et al. (2008) presented the findings of research on a new ESP technology based on diffusion charging of particles using sonic jet charging. Tests on a 20 kW wood pellet furnace gave removal efficiencies of 80% for sub-micron particles. A multiple tubular electrostatic precipitator was designed and evaluated by Intra, Limueadphai, and Tippayawong (2010). It was concluded that approximately 70% overall collection efficiency could be achieved with this simple multiple tubular design. Bologa, Paur, and Woletz (2011b) described a novel space-charge electrostatic precipitator which gave collection efficiencies in wood combustion of over 90% for particles < 1 μm.

Intra et al. (2010) described the development of a modular ESP based on the simple wire and plate concept and found collection efficiencies of 80% in a small municipal waste incinerator. However, despite these current examples, electrostatic precipitators for small scale biomass furnaces are still at a relatively early stage in their development (Obernberger & Mandl, 2011).

Increasing demand for biomass feedstock will put pressure on available wood supplies and increase the importance of non-wood feedstocks which have typically higher particulate emissions but lower precipitation efficiencies (Berhardt, Lezsovits, & Groß, 2017; Matthes, Hartmann, Groll, & Riebel, 2016). Hence, the objective of this study was to evaluate particle precipitation efficiencies across a range of biomass feedstocks, using two contrasting designs of electrostatic precipitators. The use of agricultural fuels with very high particulate emission levels and their comparison under differing ESP designs brings novelty to this research.

2. Materials and methods

2.1. *Electrostatic precipitator descriptions*

Two different types of electrostatic precipitator; an in-line and a chimney top system (Figs. 1 and 2) were tested using three different fuels with a range of particulate matter emission values ranging from very low (wood), medium (willow) and very high (tall fescue). The precipitation results were compared in terms of particulate matter (PM) size distribution.