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Particulate and gaseous emissions from different wood fuels during combustion in a small-scale biomass heating system

R.J. Olave*, E.G.A. Forbes, C.R. Johnston, J. Relf

Agri-Food and Biosciences Institute, Large Park, Hillsborough, Northern Ireland, BT26 6DR, UK

HIGHLIGHTS

- Qualifying criteria for flue gas emissions of NO_X and PM10 during wood biomass combustion are investigated.
- Willow (*Salix* spp) and Sitka spruce (*Picea sitchensis*) biomass, had differences in gaseous and particulate emissions.
- Fuel emissions is a direct result of using different types of wood biomass fuels.
- Only Sitka spruce would have qualified for the Renewable heat incentive emission criteria.

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ABSTRACT

Woodchip is widely used as fuel in dedicated biomass and, even in some conventional energy generation plants. However, there are concerns about atmospheric air pollution from flue gases emitted during wood biomass combustion, particularly oxides of nitrogen (NO_x) and particulates <10 μm diameter (PM10). In the United Kingdom (UK) a small scale biomass heat generation support scheme, the Renewable Heat Incentive (RHI), has been introduced. Qualifying criteria for this scheme have included limits for flue gas emissions of NO_X and PM10 of 150 and 30 g per gigajoule (g/GJ) of energy input, respectively. In an experiment, three locally available types of Willow (*Salix* spp) and one of Sitka spruce (*Picea sitchensis*) woodchips, showed significant differences in physical and chemical constituents, gaseous and particulate emissions. During combustion in a 120 kW biomass system, air flows, flue gas temperatures and energy output correlated with gaseous emissions, NO_x with raw fuel ash, nitrogen, phosphorus and potassium content, as did all flue gas particulate fractions. PM10 ranged from 30.3 to 105.7 g/GJ and NO_x from 91.2 to 174.3 g/GJ. Sitka spruce produced significantly lower emissions of PM10 and NO_x (27.5 and 52.6% less, respectively) than the three willow fuels, from which emissions were above the RHI emissions limits.

1. Introduction

The use of selected biomass material as a fuel to provide energy and heat through combustion is seen as a way to reduce the reliance on fossil fuels and simultaneously reduce green-house gas (GHG) emissions (Saidur et al., 2011). In the United Kingdom (UK), targets have been set to reduce NO_x and particulate matter (PM10) emissions by 55% and 30%, respectively, of the 2005 year totals by 2020 (DEFRA, 2014). Increasing the use of woody biomass and reducing fossil fuel burning is considered a feasible option under the RHI program of the Department on Energy and Climate Change to reach these targets in the UK. It is designed to incentivise small scale biomass energy heat generation by paying a premium, index linked to inflation for 20 years, to renewable heat generators (RHI, 2015). To be eligible for the RHI an emission certificate must qualify that combustion equipment and fuels produce less than 30 g per gigajoule (g/GJ) net heat input for PM10 and 150 g/GJ for NO_x (expressed as NO_2).

Quality and composition of wood fuels can vary enormously, both from inherent characteristics and production processes and these can affect emissions from combustion (Jenkins et al., 1998; Obernberger et al., 1997, 2006; Yang et al., 2005). Combustion of wood fuels, both singly and in co-firing, has been in focus in recent years as these biomass fuels are known to combust efficiently with high heat transfer and lower gaseous emissions than solid fossil fuels (Jenkins et al., 1998; Yang et al., 2005). However incomplete

* Corresponding author.
E-mail address: rodrigo.olave@afbini.gov.uk (R.J. Olave).

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combustion of the fuels can result in the release and emission of pollutant gases and particulates to the atmosphere (Williams et al., 2012). Air flow rate is a critical factor in boiler flame temperature and affects CO, CO_2 and O_2 emissions (Sartor et al., 2014). The chemical composition of biomass fuels is less complex than that of solid fossil fuels (Demirbas, 2004; Vassilev et al., 2010) though they can also have relatively high moisture content and many elements that can be problematical during combustion, especially nitrogen (N). This can directly influence gaseous nitrogenous emissions (Jenkins et al., 1998; Obernberger et al., 2006). Fuel NO_x consists of compounds of nitric oxide (NO) and nitrogen dioxide (NO_2) and is the largest component of N emissions (Obernberger et al., 2006; Sartor et al., 2014). This is related directly to fuel N content, little of which is lost to combustion ash and flue gas particles (Obernberger et al., 2006; Sartor et al., 2014). Operational temperature in small to medium sized boilers is a key factor for liberation of fuel NO_x (Jenkins et al., 1998; Yang et al., 2005; Verma et al., 2011). Fossil fuel NO_x contributes significantly to atmospheric pollution and is linked to many environmental problems whereas the contribution from biomass is much lower and potentially may reduce overall levels (Saidur et al., 2011; Demirbas, 2005; Williams et al., 2012). The combustion of biomass is a complex physical and chemical process and many factors, including fuel particle size and distribution, can contribute to the formation and emission of small particulates to the atmosphere (Jenkins et al., 1998; Williams et al., 2012; Johansson et al., 2003). These particulates, generally referred to as particulate matter <10 μm diameter (PM10), cause concern as these have been linked to increases in poor air quality around the world, especially during periods of localised high atmospheric pollution (Williams et al., 2012; Koppejan and Van Loo, 2012). Particulates <2.5 μm diameter are considered as most injurious to human health as they can penetrate deep into the human lung alveoli. These also carry a wide range of adhering chemical compounds that are known to induce inflammatory responses (Williams et al., 2012; Bølling et al., 2009).

Though emissions abatement technology and operating methods have advanced significantly in recent years (ERA-NET Bioenergy project, 2012) wide physical and chemical variations in biomass fuels still present the basic challenge to combustion and emissions (Jenkins et al., 1998; Demirbas, 2004; Williams et al., 2012). Although several sources of woodchip biomass fuels are available locally in Northern Ireland (McElroy and Dawson, 1986; Forbes et al., 2014) for heat generators eligible to enter the RHI scheme, little is known about the NO_x and PM10 status of these fuels and whether they meet the RHI emission criteria.

Therefore the aim of this study was to quantify emissions of each fuel type and relate these to the RHI criteria.

2. Methods and materials

2.1. Biomass fuel description

The two main sources of woodchip biomass fuels in Northern Ireland are 3 year harvest cycle short rotation coppice (SRC) and soft wood Sitka spruce (*Picea sitchensis*) conifers which often have higher energetic qualities than SRC willow wood (Ledin, 1996).

Four fuels were used in this experiment (Table 1), three types of willows, one of which had fine particles < 3.15 mm removed, and Sitka spruce (hereafter referred to as Sitka).

Willow chips were harvested by two methods; 1/Wcc-cut and chipped, harvested by a Class woodchip harvester; 2/Wst-whole-stem harvested (Stemster Harvester) open-air dried for about 6 months then chipped using a Heizetech woodchipper. Wfr- Wcc woodchips passed through a screening unit (Ultra Deck Screen) to remove fines <3.15 mm. Sitka was clear-felled with a Valmet 901 harvester from 40 year old stock in the farm forest, open air stored for about 24 months then chipped (Starchl 450 mobile chipper). Harvested material was dried in a ventilated floor drying bay using warm air (~10 °C > ambient) to dry to <25% moisture content.

2.2. Experimental design

The experiment was a randomised block design containing four treatments which consisted of the four different woodchip materials (Table 1). Each treatment was replicated 10 times with two consecutive combustion tests performed per day (am: pm) and randomly allocated until all of the replications had been completed. Samples of fuel weights, ranging from 30.0 kg to 44.5 kg, were combusted through the boiler ranging from 25 to 35 min until samples were burnt out. The biomass heating system consisted in a 120 kW (nominal output) (Biokompakt®-AWK/ECO) multi-fuel biomass boiler, with pre gasification included with a 3 fold air regulation, and fed from feedstock hoppers which was designed for experimental research and fully integrated within a small scale farm heat production facility (Forbes et al., 2016).

2.3. Wood chip sampling and analysis

Woodchips were sampled during fuel loading (1.0 kg minimum sample weight) using the standard methods protocol Solid Biofuels sampling (BS EN14778; 2011) (Anon, 2015). Moisture content was determined by the oven drying method- (BS EN 14774-3: 2009) with samples dried at 80 °C to a constant weight in a calibrated oven (Gallenkamp). Particle size distribution assessment was carried out following the standard procedures BS EN 15149-1; 2010 and 14774-1, using a range of certified (BS410-1:2000) sieves (Impact Laboratory Test Sieves). Dried fuel samples were milled (Fritsch Pulverisette) to <1.0 mm grain size for chemical analyses. Gross energy (GE) was analysed by bomb calorimetry (Parr 6300), ash (Ash) by flame oxidation to 550 °C in a closed combustion furnace (Vecstar), carbon (C) and nitrogen (N) content by Dumas analyser (Elementar Variomax CN). Phosphorus (P) and potassium (K) were analysed by flow injection analysis and atomic emission spectroscopy, respectively.

2.4. Combustion tests

For combustion testing a 120 kW (nominal) heat output multi-fuel biomass boiler (Biokompakt-AWK 120) was used. The boiler manufacturer's automatic settings for woodchip combustion were

Table 1
Type of material and chipping process of four types of biomass fuels used to determine gaseous and particulate emissions during combustion in a small scale biomass heating system.

Fuel	Age	Fuel source	Production processes
(Wcc)	3 years	SRC willow	Cut and chip- single operation, dry stored
(Wfr)	3 years	SRC willow	Cut & chip, fines removed, dry stored
(Wst)	3 years	SRC willow	Whole stem harvest, 6 months field storage, chipped
Sitka	40 years	Commercial forest	Clear fell logging, 24 months field storage, chipped