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Research Paper

The use of additives and fuel blending to reduce emissions from the combustion of agricultural fuels in small scale boilers

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The results of tests to determine the efficacy of fuel blending and additives to reduce emissions from the combustion of agricultural fuels are presented. It was shown that peat blended with miscanthus and tall fescue has the potential to significantly reduce both PM_1 emissions and problems related to ash melting. However, the high nitrogen content of the peat (1.5%) compared to the two agricultural fuels tested (miscanthus − 0.33 and tall fescue- 0.69) leads to increased NO_x emission with increasing proportions of peat in the blend. The results also showed that for both fuels a kaolin addition rate of 4% gave significant reductions in PM_1 emissions. With increasing peat/kaolin addition ash sintering temperature increased while potassium release decreased. With further developments in the use of additives and fuel blending it is foreseen that pellets from agricultural fuels may form a viable alternative to wood pellets.

1. Introduction

Rising oil prices and increasing concern about the impact of greenhouse gas emissions from the use of fossil fuels have stimulated interest in renewable forms of energy including biomass. Combustion is the most mature technology for biomass utilisation but emissions from biomass combustion are typically greater when compared 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). Nitrogen in the fuel is the principal source of NO_x emissions as during combustion fuel nitrogen is almost entirely converted into gaseous nitrogen and nitrogen oxides (Nussbaumer, 2003; Obernberger et al., 2003). Particles of solid carbon (soot) may also emanate from incomplete biomass combustion (Bafver, 2008). However, under conditions of complete burnout, particle emissions primarily result from the release of inorganic material from the fuel, such particles consisting mainly of K, Cl, S, Na although the principal element is K (Nussbaumer, 2003). Epidemiological studies have demonstrated a relationship between negative health effects and air pollution (Dockery et al., 1993). However, the increasing demand for biomass together with limited wood supplies are forcing markets to consider non-woody forms of biomass such as agricultural

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crops (cereal straws, energy grasses, miscanthus). Such fuels differ in their chemical composition to wood as they typically have higher ash content and higher concentrations both of ash forming elements and of elements which produce elevated levels of gaseous emissions such as nitrogen and sulphur (Nordin, 1994; Obernberger & Thek, 2004). Thus, emissions from the combustion of agricultural fuels are likely to be higher than those from the combustion of wood fuels.

Strategies which can be used to reduce emissions include the use of air staging and fuel staging (manipulation of the atmosphere in the primary and secondary combustion chambers to create optimised conditions during combustion, Salzmann, 2001) strategies. Such primary strategies can be very effective as a means of reducing NO_x emissions but are not as successful as a means of reducing particulate emissions as the primary cause of biomass particulate emissions is the chemical composition of the fuel (Nussbaumer, 2003). Particulate emissions from biomass combustion can be reduced by the use of secondary measures such as filters and electrostatic precipitators (Obernberger & Mandl, 2011). Alternatively, 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).

Combustion additives can be classified according to their chemical composition (Bafter et al., 2008). The principal additive groups are those based on calcium, phosphorus, sulphur and aluminium-silicate additives. The most popular and best understood additives are those containing lime or clay minerals (Bäfver et al., 2009; Lindström, Sandström, Boström, & Öhman, 2007; Öhman, Hedman, Boström, & Nordin, 2004). Kaolin is the most studied clay additive, it consists principally of the mineral kaolinite ($Al_2Si_2O_5(OH)_4$) and acts by binding alkali compounds to the mineral, forming potassium-aluminium silicates which have higher melting temperatures than pure potassium silicates. Boström, Grimm, Boman, Björnbom, and Öhman (2009) added either calcite or kaolin additives to oat grain prior to combustion and found substantial reductions in particle mass in the flue gases with both additives, a greater proportion of potassium was captured in ash as a result of kaolin addition. Bäfver et al. (2009) added both limestone and kaolin to oats grains and found that particle emission could be lowered by adding kaolin (2–4%). A consequence of kaolin addition was that a higher proportion of potassium was found in the bottom ash and chlorine was almost eliminated in fly ash particles. Boman, Boström, and Öhman (2008) reported that the addition of 1–2% kaolin resulted in a significant reduction in fine particle emissions from wood pellets although the addition of calcite only had a marginal effect. Bäfver, Boman, Rönnbäck (2011) reported that the addition of kaolin (3% and 6% wet basis) decreased particle emissions from the combustion of straw pellets but that there is a clear risk of over-dosing. Kaolin has been shown to be an effective additive for reducing fine particle emissions from biomass combustion. It acts by binding potassium to form high melting K–AL silicates reducing the release of potassium to flue gases.

In addition to the use of additives, the chemical composition of the biomass feedstock can be altered by blending the fuel of interest with another fuel with a different chemical composition. Lundholm, Nordin, Öhman, and Boström (2005) found that the addition of <30% peat (an accumulation of partially degraded vegetation) to biomass reduced fuel bed agglomeration. Pommer et al. (2009) also found a decrease in agglomeration when 20% peat was added to biomass but they also found a decrease in fine particle emissions and an increase in coarse emissions. The mechanism for the positive effects of adding peat was identified as the removal of potassium in the gas phase to a less reactive form. Nyström, Hedman, Boström, Boman, and Öhman (2009) added both peat with a high ash content as well as peat with a low ash content to wood biomass in different ratios. They found an increase in slagging tendency with both types of peat although the slagging tendency was considerably reduced when the low ash peat type was used. Fagerström et al. (2010) reported a reduction in fine particle and deposit forming alkali when peat was blended with straw and suggested that the capture of alkali was most probably related to the reaction of potassium with reactive silicon or clay minerals in the peat. It was suggested that slagging could be reduced, or avoided with the use of peats with high silicon to calcium ratios.

Energy crops (miscanthus, tall fescue, cocksfoot, etc.) are likely to be major contributors to renewable energy mix in the future and have been shown to have great potential to mitigate carbon emissions (Smith, Powlson, Smith, Fallon, & Coleman, 2000). Perennial grasses have proven to be good candidate energy crops, their advantage over trees is that they establish more quickly and produce an annual harvest with low moisture content (Clifton-Brown, Bruer, & Jones, 2007). However, emissions from the combustion of energy crops are a potential concern particularly if energy crops are to be utilised as a feedstock in small and medium scale combustion units. Previous research had demonstrated that additive and fuel blending strategies can be successfully used to reduce emissions from a range of biomass feedstocks (Bäfver et al., 2009; Boman et al., 2008; Lindström et al., 2007; Pommer et al., 2009). However, research to date has concentrated on biomass feedstocks such as wood, grain and straw with comparatively little work done on energy crops. The objective of our study was to quantify how emissions from the combustion of two contrasting perennial grass energy crops (miscanthus and tall fescue) could be reduced through the use of additive and fuel blending strategies. Miscanthus is already well established an energy crop while native grasses such as tall fescue have recently been proposed as potential energy crop (Finnan, 2010) which offer the advantage of reduced costs of establishment compared to miscanthus.

2. Materials and methods

For combustion of these energy crops and to ensure complete mixing it was necessary to pelletise each of the samples. Pelleting was carried out at University College Dublin's Lyon's Research Estate using a Jiangsu Dehui pellet mill (Jiangsu Dehui Machinery & Electric Equipment Co., Ltd, Jiangsu, China).

The peat for blending tests was harvested in Ireland and was received in milled form with particle size of <3 mm. The kaolin for the additive tests was in powdered form with particle size <1 mm. Miscanthus and tall fescue were firstly