Project number: 6046
Funding source: SEAI/ERANET
Date: October, 2013
Project dates: Jan 2010 – April 2013

Future low emission biomass combustion systems

Key external stakeholders:

Biomass producers, Consumers, Boiler Manufacturers, Policy Makers, Scientific Community

Practical implications for stakeholders:

Substantial reductions in gaseous and particulate emissions from biomass combustion are possible through the use of a range of strategies which include

- Air staging
- The use of mixtures and additives
- The use of electrostatic precipitators

Main results:

- Emissions of oxides of nitrogen (NOx) and particulates can be minimised by optimising the air ratio in the primary combustion chamber as well as by the use of lower temperatures in the primary combustion chamber.
- Particulate emissions can be minimised by the addition of peat to bioenergy feedstocks although NOx emissions will increase as a result.
- Significant reductions in particulate emissions are attainable when 4% of kaolin, a clay-type material, is added to miscanthus and tall fescue bioenergy feedstocks.
- Precipitation efficiencies of greater than 70% are possible in an inline Electrostatic Precipitator (ESP) system with automated cleaning, while in a chimney top, manual cleaning system high efficiencies can be achieved for willow (86%) and wood (69%) on a short term basis. However, for medium (willow >100 mg/Nm^3) and high (tall fescue > 300mg/Nm^3) emission fuels, the use of an automated cleaning system is necessary to maintain precipitation efficiencies at acceptable levels.

Opportunity / Benefit:

This project has shown that combustion emissions from a wide range of bioenergy feedstocks can be reduced. Thus, this project has improved the potential environmental footprint of biomass combustion. The project has also increased the utility and attractiveness of a range of energy crops by demonstrating that there are several ways by which the emissions from these feedstocks can be reduced.

Collaborating Institutions:

Technical University of Graz (TU Graz)

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1. Project background:

Rising oil prices and increasing concern about the impact of greenhouse gas emissions from the use of fossil fuels has 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 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. 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. Particles of solid carbon (soot) may emanate from incomplete biomass combustion. However, under conditions of complete burnout, particle emissions primarily result from the release of inorganic material from the fuel, such particles consist mainly of K,Cl, S and Na although the principal element is K.

Epidemiological studies have demonstrated a relationship between negative health effects and air pollution. However, increasing demand for biomass together with limited wood supplies are forcing markets to consider non-woody forms of biomass such as agricultural crops. Such fuels differ in their chemical composition to wood as they typically have a 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. Thus, emissions from the combustion of agricultural fuels are likely to be higher than those from the combustion of wood fuels. There is increasing concern that pollutant emissions from biomass combustion will reduce the benefit of the principal environmental driver for biomass utilisation, that of reducing emissions of greenhouse gases.

2. Questions addressed by the project:

- Can emissions from biomass combustion be reduced?
- Can a range of energy crops be used as feedstocks for biomass combustion without significant effects on air quality?

3. The experimental studies

Experimental Equipment

The combustion experiments were conducted at Oak Park, Carlow. An ETA Hack35 (ETA Heiztechnik GmbH, Hofkirchen, Austria) tilting grate biomass boiler with a rated output of 35kW and the capability to recirculate flue gas beneath the combustion grate was used for the combustion tests. The boiler was ignited and the temperature limited to 900^{o}C at steady state using flue gas recirculation before the commencement of tests. The boiler was then run for one hour in this state, during which the particulate and gaseous emissions were monitored. This test was repeated 5 times for each of the pellet types.
Gaseous emissions were measured using a Horiba portable gas analyser with a heated sampling line. Particulate emissions were measured using a Dekati 3 stage low pressure impactor with 10 µm, 2.5 µm, 1 µm and filter collection stages. This method of particulate sampling involves a known quantity of flue gas being drawn across the impacter under isokinetic conditions and the weighing of impacter plates and filter before and after testing.

Feedstocks

Five bioenergy feedstocks were used in the experiments although not all feedstocks were used in all experiments. The five bioenergy feedstocks were: wood, willow, miscanthus, tall fescue and cocksfoot. Wood, willow and miscanthus were generally combusted in chip form while tall fescue and cocksfoot were pelleted prior to combustion.

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Experiments
Air Staging Experiments: Three separate air staging experiments were carried out to determine the effect of the following parameters on particulate and gaseous emissions:
Test 1: Primary lambda (0.4, 0.6, 0.8, 1.0 and 1.2)
Test 2: Primary Combustion Chamber Temperature (900, 1000 and 1100 ^{0}C).
Test 3: Overall excess air ratio (4, 6, 8, 10, 12 %).


Air Staging Experimental Set-up

Mixture and Additive Experiments: Peat was added to miscanthus and tall fescue feedstocks in percentages from 0 to 100%, both components of the mixture were mixed before being pelleted prior to combustion. A clay-based additive called Kaolin was also mixed with either miscanthus or tall fescue in percentages of 0, 1, 4, and 7% prior to pelletisation. The peat for blending tests was harvested in Ireland and was received in milled form with a particle size of less than 3 mm. The kaolin for additive tests was in powdered form with a particle size less than 1 mm. Miscanthus and tall fescue were firstly milled for ease of mixing in a Jiangsu Dehui hammer mill with a 3 mm screen size.

Electrostatic Precipitator Experiments: Two different types of electrostatic precipitator; an inline and a chimney top system, were tested using three different fuels which gave a range of particulate matter emission values ranging from very low (wood), medium (willow) and very high (tall fescue). The Schrader Al-Top (Schrader, Hemsack, Kamen, Germany) works on the principle of using a high voltage electrode (28kV) at the flue gas inlet to impart a negative charge to the particles. An automated cleaning system is used by this system. The Oekosolve "Oekotube" (Oekosolve AG, Industriestrasse, Ruggell, Liechtenstein) is a chimney top type ESP. A long electrode (1.3m) is inserted into the chimney and the control system is mounted outside. The electrode imparts a charge to the particulates which are collected either on the electrode or on surrounding surfaces.


AL-TOP


Oekotube

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4. Main results:

- It was shown that by varying the lambda value in the primary combustion chamber, NO_x emission reductions of between 15% (wood) and 30% (miscanthus) and particulate emission reductions of between 16% (cocksfoot) and 26% (wood) are possible. For all fuels, both NOx and particulate emissions were minimised at a primary lambda of 0.8. Particulate emissions from miscanthus increased with increasing temperature in the primary combustion chamber, NOx emissions from miscanthus and from willow also increased with temperature. Overall excess air ratio has no effect on emissions as no significant differences were found for any of the fuels at any of the different excess air ratios.
- Peat has a diluting effect on particulate emissions with a very strong linear relationship between percentage peat addition and particulate emission reduction demonstrated for both miscanthus (r^2 – 0.98) and tall fescue (r^2 – 0.99).
- For both miscanthus and tall fescue it was found that a kaolin addition rate of 4% gave significant reductions in particulate emissions. For miscanthus, a reduction of over 50% in particulate emissions (from 50 mg/Nm^3 to 24 mg/Nm^3) was demonstrated, particulate emissions from tall fescue fell by over 40% (from 340 mg/Nm^3 to 200 mg/Nm^3) after kaolin addition. Ash sintering temperature increased while potassium release decreased with increasing peat/kaolin addition.
- For all fuels, testing showed that precipitation efficiencies of greater than 70% are possible in an inline ESP system with automated cleaning, while in the chimney top, manual cleaning ESP system high efficiencies can be achieved for willow (86%) and wood (69%) on a short term basis.
- It was shown, that for low emission fuels such as wood (< 10mg/Nm^3), acceptable precipitation efficiencies (approx. 70%) could be achieved and maintained over a long time period on both automated and manual ESP systems. For medium (willow >100 mg/Nm^3) and high (tall fescue > 300mg/Nm^3) emission fuels it was found that the use of an automated cleaning system is necessary to maintain precipitation efficiencies at acceptable levels.

5. Opportunity/Benefit:

This project has shown that combustion emissions from a wide range of bioenergy feedstocks can be reduced. Thus, this project has improved the environmental footprint of biomass combustion. The project has also increased the utility and attractiveness of a range of energy crops by demonstrating that there are several ways by which the emissions from these feedstocks can be reduced.

6. Dissemination:

Future Low Emission Biomass Combustion Systems – Final Report
Low Emissions Operation Manual for Chimney Stove Users
Guidelines for Low Emission Chimney Stove Design
Design and Operation Concepts for Low Emission Biomass Grate Furnaces based on Advanced Air Staging
Guidelines for the Design and Application of Particle Precipitators for Residential Biomass Combustion
Reports available on http://www.teagasc.ie/energy/research/BiomassCombustion.asp

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