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Cereal grains and crop residues as feedstocks for combustion

Key external stakeholders:

Energy crop and tillage farmers, biofuel pellet manufacturers, solid biofuel suppliers, biomass boiler manufacturers, consumers, policy makers, scientific community

Practical implications for stakeholders:

The significance of this research for stakeholders is as follows

- *Farmers* may be able to take advantage of a new market for their tillage crops and energy crops
- *Policy Makers* can now take into account that a wide range of biomass feedstocks can be used for combustion. These feedstocks can make a contribution towards national bioenergy and greenhouse gas targets.
- *Industry* can use to data from this project to assess the suitability of a range of biomass feedstocks for combustion in different biomass boilers. Data from this project can also be used to design biomass boilers suitable for more challenging feedstocks
- *Consumers* can benefit from this project from the availability of information on biomass feedstocks which they may be offered as fuel for their boilers
- *Scientific Community* benefits from this project as new information is available on the physical and chemical properties of a wide range of biomass feedstocks as well as on their combustion and emissions. The project has also shown how techniques such as thermogravimetric analysis and differential thermal analysis can be used in boiler design.

Main results:

The project established that a wide range of biomass feedstocks can be burnt in boilers. The most difficult materials to burn are those which exhibit properties of high moisture, low bulk density and poor flow properties. However, these properties can be mitigated by drying and densification. Materials with low ash melting points such as *Miscanthus* need to be combusted in boilers which employ either flue gas recirculation, water cooled grates or mechanical agitation of clinker.
Successful combustion of cereal grains depends on species, agronomic practice and moisture content. Oats and triticale can be successfully combusted at moisture contents below 20%, other grain species are less suitable for combustion. The cultivation of cereals for combustion should ensure that grain nitrogen levels are as low as possible in order to avoid high emissions of oxides of nitrogen from combustion.

Opportunity / Benefit:

The use of biomass for combustion offers a number of potential benefits which include import substitution and greenhouse gas mitigation in addition to offering an alternative enterprise for farmers. The project established that a wide range of biomass feedstocks can be burnt in boilers and has identified the most challenging feedstocks. However, the project has established how the most deleterious properties of challenging feestocks can be mitigated as well as the combustion technologies most suited for these feedstocks. Thus, the project has categorized the suitability of a wide range of feedstocks for combustion but also demonstrated how more challenging feedstocks can be utilized. Hence, the project has increased the utilization of a range of biomass feedstocks, this benefit is available to all stakeholders.

Collaborating Institutions:

University College Dublin

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1. Project background:

National and international plans to increase the provision of renewable energy and to mitigate greenhouse gas emissions will require a substantial increase in the use of biomass feedstock for the generation of heat and electricity. It is desirable that such feedstocks be produced locally. In Ireland, the supply of wood and forest residues will be insufficient to meet all demands so therefore, other biomass resources such as energy crops, agricultural crop residues and by-products and wastes will be needed. Biomass materials that are available or could be grown in significant quantities in Ireland include short-rotation willow, miscanthus, cereal straw and cereal grains.

2. Questions addressed by the project:

Could the combustion characteristics of a broad range of biomass materials, that could be used as solid fuels, be examined? In particular,

- Could the physical and chemical characteristics of the experimental solid biomass fuels be determined?
- Could thermogravimetric and differential thermal analysis techniques be used to determine the patterns of mass loss and heat flux from the combustion of each of the fuels?
- Could the combustion performance of the experimental solid biomass fuels in full scale boiler trialsbe evaluated?

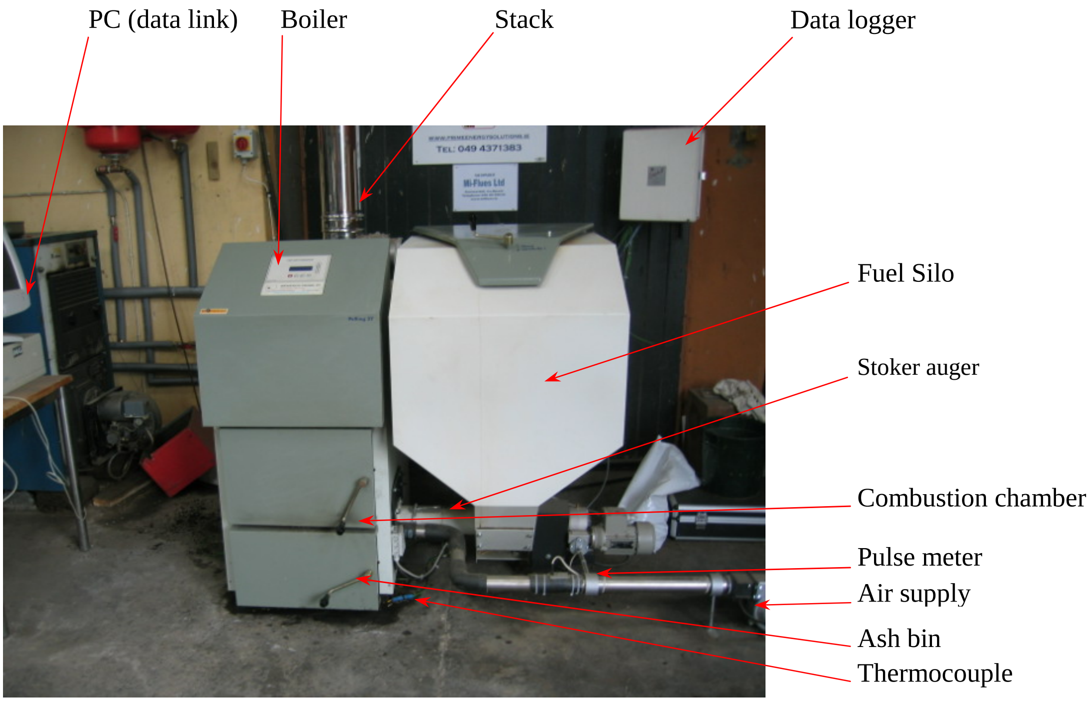
3. The experimental studies:

The combustion characteristics of a broad range of potential biomass feedstock materials were tested in this project. The biomass materials tested included wood, *Miscanthus*, willow, cereal and rape straws, rape cake and cereal grains. There were three tasks in the work programme

(i) **Laboratory analysis** of the physical and chemical properties of the experimental materials;

(ii) **Thermogravimetric analysis (TGA) and Differential Thermal Analysis (DTA)** were used to study the thermal decomposition of the experimental material with the objective of useing the data for a more analytical approach to biomass fuelled boiler design. These two techniques are carried out with the same equipment. In this procedure, a small sample of the experimental material is burnt during which the mass loss and the heat fluxes to and from the sample are quantified. The resulting data allows the calculation of mass loss and heat flux during the different phases of the combustion process (dehydration, volatilization, oxidation and decomposition)

(iii) **Boiler Tests** The experimental materials were fired in either of two types of boilers (KWB 100kw boiler, Benekov 15kw boiler), their performance and emission measurements were used to evaluate the efficacy of the material as a feedstock for combustion.



Benekov boiler in test configuration

4. Main results:

The following are the conclusions from the project:

- Boiler performance is affected by a wide range of fuel properties. The effect of some properties, e.g. gross and net calorific values and moisture content, are reasonably predictable; the effects of other properties, such as particle size, densification method and ash melting behaviour, are more complex and require a deeper understanding of the combustion process. Boilers are already on the market that can cope with wood-derived fuels of suitable moisture, particle size and bulk density. However, biomass materials with high moisture, low bulk density, poor flow properties and low ash melting points present major difficulties. The physical problems can be mitigated (though at some cost) by drying, size reduction and densification. For low-melting-point materials, control of the temperature within the combustion chamber is critical. Boilers which pocess the ability to reduce the temperature in the combustion chamber (eg flue gas recirculation, water cooling) can handle a wide variety of fuels with ash-related problems.

- Woody materials are the least problematic biomass fuel. Such material provide the highest heat output and thermal and combustion efficiencies and the cleanest stack emissions, and can be burned in a wide range of boiler designs.

- Loose *Miscanthus* and cereal straw fuel present some difficulties mainly due to their low bulk density and low ash melting temperature. The former can be overcome by densification methods such as pelleting, the latter makes considerable demands on the design of the boiler combustion chamber and controls e.g. flue gas recirculation, water-cooled grates, mechanical ash removal etc. The use of additives containing calcium may be beneficial, though this will lead to an increase in ash content.

- Successful combustion of cereal grains depends very much on the grain species, its moisture content and the agronomic practices used in its production. Oats and triticale can be successfully combusted at 15% moisture; if they are harvested at moistures below 20% they can still be burned; heat output and emissions will be adversely affected although it is unlikely that this will justify the cost of drying. To keep NO_x levels low, agronomy practices should be as for malting barley. Barley and wheat dried to 15% can be burned, but no attempt should be made to burn them at higher moistures.

- TGA/DTA analysis can provide detailed information on the progress of the combustion process through its various stages, and helps to explain the differences in the combustion performance of different biomass materials. Taken along with property analyses, it allows the calculation of boiler design variables such as the separation of primary and secondary air and combustion chamber volume requirements for efficient combustion. Further study may lead to the quantification of other boiler design and operation parameters, and allow a more analytic approach to be made to the design and operation of boilers burning specific fuels.

5. Opportunity/Benefit:

The use of biomass for combustion offers a number of potential benefits which include import substitution and greenhouse gas mitigation in addition to offering an alternative enterprise for farmers. The project established that a wide range of biomass feedstocks can be burnt in boilers and has identified the most challenging feedstocks. However, the project has established how the most deleterious properties of challenging feestocks can be mitigated as well as the combustion technologies most suited for these feedstocks. Thus, the project has categorized the suitability of a wide range of feedstocks for combustion but also demonstrated how more challenging feedstocks can be utilized. Hence, the project has increased the utilization of a range of biomass feedstocks, this benefit is available to all stakeholders.

6. Dissemination:

The results of the project were disseminated to the public at the several events, including; Teagasc Open Day, Oak Park, Carlow, June 26th 2007 and June 25th 2009; Bioenergy 2007, Carlow and Bioenergy 2008, Athenry; Green Energy Fair, Gowran, Co. Kilkenny, 27th-29th October 2007.

Main publications:

Keppel, AR (2010) Characteristics of Cereal Grains and Crops Residues as Solid Biomass Fuel. MEngSc, University College Dublin.

Keppel AR (2008) Cereal grain as a fuel. In. Farm Energy. Farm Diversification Manual. ISBN 1 84170 507 1

Cereal Grains as a Boiler Fuel (2006) Teagasc Tillage Specialists Factsheet No 5.

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