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COST-EFFECTIVE SCREENING OF BIOMASS MATERIALS FOR CO-FIRING

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ABSTRACT: ECN developed a number of fuel characterisation and lab-scale testing methods to evaluate specific properties and behaviour of biomass materials for co-firing with coal. Methods were developed or improved to characterise fuel particle size and shape distribution, fuel mineral size distribution, fuel reactivity and burnout, and fly ash quality with regard to utilisation and ash deposition. The tests can be applied at relatively low cost to screen potential (biomass) fuels, to improve their performance by fuel blending and to support full-scale operation by trouble shooting.

Keywords: co-combustion, fly ash, biomass characteristics

1 INTRODUCTION

A promising route to achieve CO_2 reduction is the use of short cycle carbon containing fuels, which can be generally classified as biomass fuels. These fuels have the thermodynamic potential to replace fossil fuels, but operational and environmental problems may dramatically affect the combustion system. To focus on the industrial problems of biomass fuel application, one requires, in advance, detailed knowledge of the typical combustion behaviour of these fuels. The objective of this work has been to provide staff of coal-fired power plants with cost-effective methods for assessing the co-firing potential of biomass materials.

The work was conducted within the framework of the EU-project BioFlam [1], in which sixteen electricity producers and R&D organisations from seven European countries dedicated R&D efforts to further advancing the knowledge base on biomass co-firing and, specifically, deriving cost-effective screening tools.

ECN has focused on developing advanced fuel characterisation as well as lab-scale fuel testing methods to assess various conversion aspects. This comprises the development of a new method to determine the particle size and shape distribution of ground mixtures of coal and biomass, to enable assessment of milling performance for such binary mixtures. In addition, Computer Controlled Scanning Electron Microscopy (CCSEM) has been used to determine the mineral speciation of binary fuel mixtures, which gives a relevant basis for predicting slagging and fouling processes. In particular, existing fuel preparation procedures have been adapted for fuel mixtures including biomass materials.

With respect to lab-scale fuel testing, various aspects of pulverised-fuel (pf) combustion have been addressed at ECN over the past years [2-4]. Generally, the aim is to deliver a “fingerprint”, which represents the fuel’s behaviour in a full-scale furnace. Within the BioFlam project, focus has been put on the assessment of potential burnout and fly ash utilisation problems.

In this paper, the main results are summarised. A more detailed description can be found elsewhere [5].

2 FUEL CHARACTERISATION

2.1 Particle Size and Shape Distribution (PSSD)

Many secondary fuels are difficult to grind and produce irregularly shaped, up to millimetre size particles. Obviously, the trajectories, heating and conversion of these particles will be different compared to the fairly uniformly shaped, pulverised coal particles. Measurement of their PSSD is important to appreciate these differences and to be able to predict their different behaviour. Optical microscopy with digital image processing software has been applied to obtain size resolved information on the shape of particles in a ground fuel sample. As this application had never been tried before, several problems had to be overcome.

A representative sample of fuel particles was obtained by creating an emulsion, which is held between two standard microscope glass plates. This procedure effectively eliminates problems of sample inhomogeneity caused by density induced particle segregation (a drawback of most other techniques). Moreover, the pressure applied to the glass plates gives control of the dispersion of the particles and thereby avoids particle contact resulting in erroneous particle size and shape data. Visible light passes the sample to create a projection of the particles, which can be analysed and translated into size and shape information by dedicated software. About 40,000 particles can be analysed per sample. The optimal depth of field was found to be at 2.5 magnification, giving a lower detection limit of ~14 µm. A typical example is shown in Figure 1.

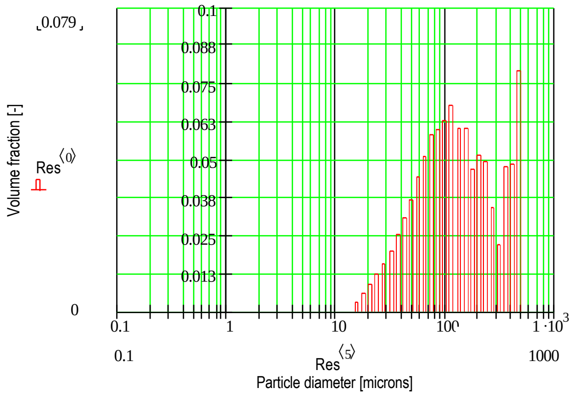


Figure 1. Left: sieve fraction >180 µm taken from a blend of Polish pulverised coal with 10% wood particles; right: the large wood particles result in a bimodal size distribution of the whole blend.

The technique has not been developed as an alternative to more common techniques for particle size distribution measurement as the ones based on light diffraction (e.g. Malvern Mastersizer). It should rather be used as a method to obtain data on the size and shape properties of especially the larger size fractions, which is where biomass fuel particles are expected to differ mostly from pulverised coal particles.

Several samples of coal and coal-biomass mixtures have been analysed. For all samples, it was found that the average shape factor (a measure for particle sphericity) decreased as a function of particle size. Shape factors were found to range from close to 1 for very small particles down to 0.2 for large particles. From photographs of sieve fractions of coal/wood and coal/cocoa mixtures, it was concluded that the low particle shape factors were associated with an either elongated (fibrous, esp. woody materials) or flattened (flaky, e.g. this specific cocoa residue) shape.

2.2 Mineral Size Distribution (MSD)

Coal typically contains 5-20% ash forming inorganic matter, of which more than 90% usually is mineral. The chemical type and bonding to the carbon matrix determine how the inorganic matter is released to the gas phase and which ash particles will form during combustion. The size and composition of individual ash droplets/particles determine the behaviour of the ash. Therefore, a detailed analysis of a fuel's inorganic matter yields important information for predicting potential ash related problems such as slagging, fouling, DeNOx catalyst poisoning, particulate emissions or ash quality.

Computer-Controlled Scanning Electron Microscopy (CCSEM) can be used to determine the Mineral Size Distribution (MSD) of coals. The output of such an analysis is the normalised mass distribution of some 25 mineral types, divided over particle size bins of 2-4, 4-8, 8-16, 16-32, 32-64 and 64-128 µm.

Clean biomass materials may contain specific – typically calcium or silicon-based – biominerals, but the major part of other elements is usually found as dispersed salts or organically bound compounds. Harvested or waste biomass materials may also be contaminated with sand and clay particles. Since the biominerals and the external contamination may both significantly contribute to the total inorganic matter, ECN's CCSEM procedure has been adapted to accommodate the analysis of biomass materials.

In order to perform a CCSEM analysis, a sample (preferably 'as fired') of ground fuel is dispersed and embedded into resin. After hardening, the resin block is cut, polished and carbon-coated for microscope analysis. The specific problem of particle segregation as a result of the different densities of coal and biomass was overcome by rotating the resin holder with the particle/resin emulsion. Applying a low speed to avoid segregation by centrifugal forces resulted in workable samples with no visual segregation of biomass particles.

The procedure was successfully applied to a pulverised Polish coal and to blends including 10% wood and cocoa. While the presence of the wood in the coal/wood sample did not significantly change the mineral size distribution of the sample, a distinct influence was found of the cocoa in the coal/cocoa sample. The mineral size distribution showed an increased concentration of K-rich minerals, which agrees with the relatively high concentration of potassium in cocoa. The results demonstrate the feasibility and usefulness of CCSEM analysis applied to fuel blends with biomass.

3 LAB-SCALE FUEL TESTING

In comparison to advanced fuel characterisation techniques (as the ones outlined above), fuel testing on a laboratory scale is considered the next level of fuel evaluation, optionally followed by pilot-scale testing and finally full-scale trials. The lab-scale testing is particularly useful to evaluate the conversion behaviour of fuel and ash under well-known conditions. Various lab-scale fuel testing methods have been developed at ECN over the past years [2-4], most of them involving the use of ECN's Lab-scale Combustion Simulator (LCS). In this project, methods have been developed in particular to assess potential burnout and fly ash utilisation problems.

3.1 Fuel reactivity and burnout

As described above, the particle size and shape of biomass fuels may be quite different compared to pulverised coal particles. This affects the fluid dynamic behaviour of fuel particles (particle trajectories) in a furnace, but also the rate of combustion, including the final conversion or burnout. At typical combustion temperatures of 1300-1500°C, chemical kinetics is seldom rate limiting. In practice, a combination of internal and external mass transfer of oxygen to the fuel particle surface determines the overall reaction rate. In turn, these processes greatly depend on properties such as particle size, shape, internal porosity, etc.

Fuel reactivity nor burnout can be reliably predicted from first principles. Still, fuel evaluation in these terms is important since they can have a significant impact on the overall plant economy in terms of (fuel) efficiency and the economic value of the ash produced (which relates to the content of unburned carbon). Therefore, a lab-scale test method was developed, based on the following considerations.

The reactivity and burnout of a pulverised fuel is largely determined by the temperature and composition of the surrounding gas during combustion. After 2-3 seconds reaction time, pulverised coal particles typically achieve a burnout of 99.5% or higher. Apart from efficiency considerations this level of burnout is needed to comply with the requirement of maximum 5% carbon in ash for cement production.

Initially, fuel residence times in the LCS were limited to a maximum of approximately 1 second, reflecting the typical capability of many drop tube test facilities around the world. To meet the aforementioned requirement of 2-3 seconds reaction time to achieve practical levels of burnout, the LCS was fundamentally redesigned. A schematic of the new design is shown in Figure 3.

Essentially, the objective was met by a net reduction of the fuel particle velocity by a factor of three, thus tripling the fuel residence time within the length (1 m) of the existing facility. For pulverised fuel particles with a size of up to approximately 200 μm, the gas-particle drag force controls the particle velocity; so, the extended fuel residence time can be realised by a reduction of the volumetric gas flow rate. After devolatilisation, about two-thirds of the gas flow is vented from the system and the remaining one-third (which also holds the fuel particles) continues to flow down, into the main combustion area of the facility. Both the shape of the ceramic cone as well as its vertical placement have to be chosen carefully in order not to disturb the gas flow in the system. The volumetric flow rate of the gas holding the fuel particles – and thereby the fuel residence time – is carefully controlled with a gas pump. A special electric furnace was designed to allow for the venting of hot flue gas past the heating elements and through the furnace roof.

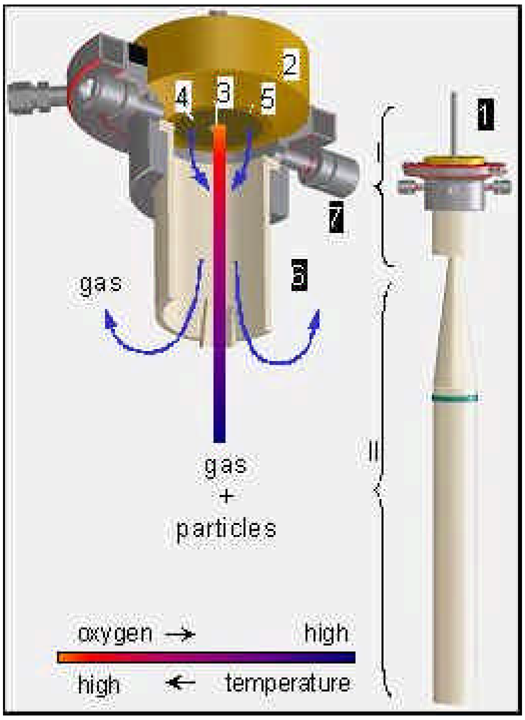


Figure 3. Schematic of the new Lab-scale Combustion Simulator. Legend: I Devolatilisation zone; II Combustion zone; 1 Solid fuel feed; 2 Flat flame gas burner; 3 Inner burner; 4 Outer burner; 5 Shield gas ring; 6 Reactor tube; 7 Optical access.

Samples of partly combusted fuel particles are obtained using a vertically adjustable probe. With this procedure the conversion of various fuels could be measured over a wide range of reaction times, up to nearly complete burnout. While in the previous set-up the combustion of coal particles was limited to typically 70%, in the new design, conversions of up to 99.8% were obtained for the same coal at an average particle residence time of 3 seconds.

3.2 Fly ash quality

The procedures for testing the quality of fly ash from pulverised-coal firing are described in the European standard EN-450 "Fly ash for concrete - definitions, requirements and quality control." In addition to this, a Dutch recommendation (CUR-70) has been drafted which includes testing fly ash from pulverised coal with a maximum mass fraction of 10% secondary fuel. The recommendation gives procedures, which can be used to assess the conformity of such fly ashes with common (coal-derived) fly ash. In concrete terms, the fly ash should at least be equivalent to common fly ash, which complies with EN-450 and CUR-70. The tested properties according to CUR-70 are:

1. Compliance EN-450:
   1.1. Chemical requirements:
      – Carbon content (LOI) - water requirement (LOI 815, as fractional mass loss ≤ 5%)
      – Chloride - corrosion steel reinforcement (mass fraction ≤ 0.1%)
      – Sulphate - thaw-frost resistivity (mass fraction ≤ 3%)
      – Free CaO (mass fraction ≤ 2%), reactive SiO_2 (mass fraction ≥ 25%) - cementitious properties
   1.2. Physical requirements:
      – Fineness (mass fraction 60% ≤ 45 μm), activity index, shape stability, density (± 150 kg/m^3)
2. Application in prestressed concrete
3. Binding agent factor
4. Conformity investigation with certified fly ash:
   4.1. Durability (thaw-frost cycle, Cl-permeability)
   4.2. Impact on additives (flowability, bubble agent, binding time retardant)

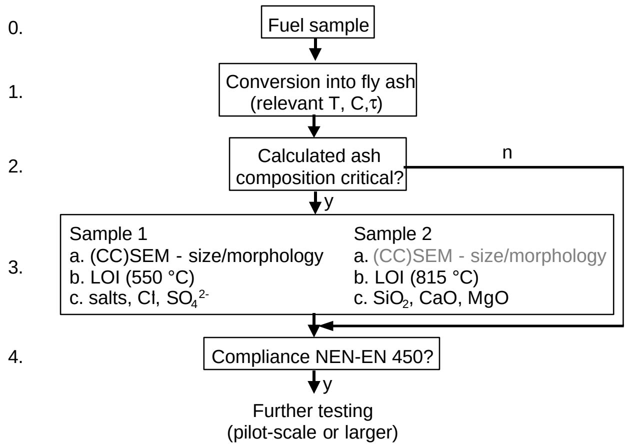
Applied properties such as 2, 3 and 4 can be tested only provided that sufficient amounts (few to tens of kilograms) are available, which requires at least pilot-scale testing. However, many of the properties described in EN-450 can be assessed by the analysis of fly ash samples produced in a representative lab-scale test. This allows for a much wider initial screening of potential fuel candidates against very low cost. And, in addition, various fuel blends can be tested easily in an attempt to identify the 'better' fuel combinations. This led to the lab-scale fly ash quality assessment procedure shown schematically in Figure 4. The development of this procedure included the development of several alternative analysis procedures for those cases, where the standard analysis suggested by EN-450 could not be applied due to the limited amount of fly ash produced.

4 CONCLUSIONS

New and improved fuel characterisation and lab-scale fuel testing methods have been developed, which allow low-cost initial screening of biomass materials for co-firing. This includes:

– Determination of particle size and shape distribution;
– Improved sample preparation technique to allow CCSEM analysis of coal/biomass mixtures;
– Lab-scale testing of fuel reactivity and burnout;
– Lab-scale co-firing tests to allow initial assessment of fly ash quality.

The methods can be applied at relatively low cost to screen potential fuels, to improve their performance by fuel blending and to support full-scale operation by trouble shooting. The individual tests, including ash deposition tests developed earlier, are currently being integrated into an overall empirical biomass co-firing assessment method, the so-called Co-firing Assessment Tool (CAT).



0.	Fuel sample procurement and standard analysis.
1.	Lab-scale combustion test with fly ash sampling for further analysis and testing.
2.	Identification of fly ash properties, which are potentially critical and require additional analysis.
3.	Execution of various analyses on 1-2 fly ash samples.
4.	Evaluation of fly ash properties for compliance with NEN-EN450.

Figure 4. Lab-scale fly ash quality assessment procedure.

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