Commentary

Biomass firing: Danish experiences

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Denmark has a long-standing objective to reduce carbon dioxide emissions through increased use of biomass for power generation. The chosen biomass, straw, posed significant new challenges for materials and combustion technology, and has also required development of supply chain management. An interdisciplinary approach, involving research organisations and companies from several sectors of industry, has been developed to overcome these requirements. Key achievements of this research and development programme and ongoing targets are reviewed.

In the early 1990s, the Danish government pledged to reduce carbon dioxide emissions by 20%, based on the 1988 level, by the year 2005. To obtain this goal more biomass was to be used by the power producing companies, since biomass is considered CO_2 neutral due to its short time of regeneration compared with fossil fuels. This objective resulted in the1993 biomass agreement between the utility operators (Elsam and Energy E2) and the government, under which power plants are required to utilise 1·4 Mt biomass for power production. The extensive research and development programme in the area of biomass firing is a direct result of this agreement. Introduction of a new type of fuel cannot be implemented from one day to the next. The new fuel has to be followed from cradle to grave – from harvesting of biomass and handling, to combustion, emissions control and utilisation of the ash products. Unlike its Scandinavian neighbours, Denmark does not have an abundance of natural forestry resources so an alternative biomass source, straw, was selected. At that time the available solutions to realise the goals of the biomass agreement were associated with high risk factors, especially with the burning of straw. Therefore it was necessary to implement an extensive development and demonstration programme for biomass firing to meet the terms of the biomass agreement.

Biomass as a fuel

At the start, handling and combustion of straw had the highest priority since there was no international experience in this field. The biomass development programme can be divided into components: use of biomass as a fuel; and combustion technology. The first area involves biomass resources, delivery chains, characterisation of biomass, health and safety aspects, and handling. At the outset of the biomass development programme, this area was central since assessment of the available amounts of straw and woodchip for energy producing purposes and investigation of biomass combustion properties was necessary to start to implement the biomass agreement.

Compared with coal, biomass has a low energy density and is difficult to handle. In recent years, there has been a focus on European standardisation work for solid biofuels in order to ensure that the emerging standards reach a high professional level and therefore will be useful when trading biomass internationally. Further improvement of the working environment for those handling biomass is also an ongoing activity.

Biomass has a chemical composition causing significant deposit formation during combustion and post-combustion, which results in acute slagging and fouling of the plant. This can lead to reduced heat transfer, blockage within the plant and increased downtime for the removal of deposits. The alkali salt deposits also cause corrosion of metallic components.

The previously well documented corrosion mechanisms and corrosion rates for solid fossil fuels proved unsuitable to predict corrosion when burning straw. Straw has been found to be one of the most corrosive types of biomass, providing corrosion problems not previously encountered with combustion of fossil fuels. When straw is burned, sulphur dioxide and potassium chloride are emitted in the gas phase and the presence of these species results in corrosive deposits condensing on vulnerable metallic surfaces such as superheaters. These deposits contain potassium chloride which, when reacted with sulphur dioxide, generates chlorine species that attack the metal. The generally accepted rule that a higher chromium containing alloy gives better corrosion resistance does not apply here: in fact quite the reverse.

Combustion technology

Development of combustion technology has followed two specific routes: grate firing and co-firing in fossil fuel fired plants. For both routes, handling and feeding of straw has been a significant hurdle and essential progress has been made through collaboration between power plant operators and biomass suppliers. Grate firing technology has been developed as a collaboration using boiler manufacturers' know-how, power plant operational experience and contributions from the power companies research and development departments. For co-firing of biomass at Studstrup, Elsam has developed most of the technical solutions. Co-firing of biomass in a circulating fluidised bed boiler has also been investigated; however, due to corrosion and erosion problems as well as problems with selling the byproduct flyash, this has not been pursued further. Over the past decade, the research and development work into grate firing and co-firing has been extensive and the two technologies have now been developed to give viable technical solutions. However, there is still a need for further development and optimisation. Thus a range of current research and development projects include such topics as combustion, control,

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corrosion, deposition, flue gas cleaning and utilisation of residual products.

Development work has been possible only through extensive collaboration between power companies (Elsam and Energy E2), biomass suppliers, boiler manufacturers, universities and other scientific institutes. An important aim of the development work has been to establish a strong connection between fundamental theoretical knowledge built up at universities and scientific institutes and practical plant operation experience. This has been achieved by involving universities and institutes in measurement campaigns at the plants.

Research and development work in the biomass field was first financed by power plants with contributions from the Danish Ministry of Energy. Now the majority of the research and development is now financed by PSO – public service obligations. A percentage of the tax paid by consumers for their heat and electricity is channelled to pay for various research and development projects. In addition, the power companies have contributed significantly to development of grate firing technology, both by exchanging knowledge and experience with boiler manufacturers and by taking on economic risk in the building of new plants with new superheater designs, higher steam temperature and pressure and other improvements. This has in some cases led to unforeseen shutdowns; this loss in operation has been borne by the utility companies themselves.

Progress to date

Extensive investigations on the procurement and properties of biomass as a fuel have been conducted, with the results listed below:

- available biomass and woodchip in Denmark have been surveyed and perspectives for cultivation of energy crops assessed
- supply chains for straw and woodchip have been optimised
- systems for checking the received biomass have been optimised
- investigations of working environments when handling biomass have been undertaken and recommendations and measures to minimise dust and reduce inhalation of dust particles have been compiled
- fuel properties of Danish straw and wood chips have been analysed, including the influence of the climate and cultivation conditions on the content of corrosive species in the straw.

Grate firing plants have undergone significant development, leading to increased electrical efficiency and greater reliability, which in turn has contributed to minimisation of risk and increased profitability of biomass combustion. In this context a range of research and development activities have been undertaken, which have built up detailed fundamental knowledge and contributed to problem solving in the following areas:

- corrosion and materials selection
- deposit formation
- building up a detailed knowledge of combustion chemistry for grate firing, which will provide the foundations to solve problems relating to corrosion, emissions and residual products
- advanced CFD (computational fluid dynamics) modelling
- development of processes to produce liquid fertilisers from straw flyash, etc.

Co-firing of straw and fossil fuels has been one of the most important areas of research and development resulting in an increased level of biomass firing. Development in the following areas has contributed to solving actual problems in co-firing:

- optimisation of straw feeding systems
- use of co-firing ash by the concrete and cement industries
- SCR (selective catalytic reduction) catalysts that do not suffer from deactivation
- overcoming the risk of chlorine corrosion in superheaters
- survey of alkali-chlorine chemistry to optimise operating parameters
- development of CFD modelling for combustion optimisation.

Future research and development

Today the terms of the biomass agreement are being fulfilled such that research and development initiatives in biomass combustion now focus on continued optimisation and further development of the plants in operation. With the increasing price of fossil fuels and the greater cost of carbon dioxide emissions, biomass is in certain areas a competitive fuel and there is therefore a need for continued research and development to support the introduction of new biomass types and facilitate greater utilisation of biomass in power plants. Already acquired knowledge is a prerequisite for further, more effective exploitation of biomass so that it can be used to fulfil continued demands for reduction of carbon dioxide emissions.

Thus, the goals for future research and development initiatives in the biomass area include:

- building on present knowledge on quality and access to both existing and potential biomass resources, to optimise exploitation of the biomass market and the potential for reduction of carbon dioxide emissions in heat production. In addition, the development of means to produce a liquid fuel such as bioethanol from biomass is required
- to optimise and develop current biomass fired plants, to improve competitiveness, to minimise risks of downtime and to establish such plants more strongly both within Denmark and internationally
- to develop combustion and gasification technology which supports the use of a wide spectrum of biomass types.

Research and development into biomass combustion has been extensive and a high level of knowledge has been reached in many areas. However, there is continual need to increase efficiency of the use of biomass. It is also important that development work is conducted in close collaboration with universities, suppliers, plant operation staff, and power plant research and development personnel.

In the area of fuel, future research areas of interest are characterisation of new biomass types, handling new types of straw bales, and moisture measurements and on-line element analysis.

In the combustion area, improved CFD modelling is required that includes ash deposition, so that fuel and ash deposition interactions can be better understood. Improved CFD modelling is also required to incorporate other types of combustion, and also co-firing.

A more interdisciplinary approach into how corrosion is linked to the exact composition of chloride and sulphate in the deposit is needed to assess what is the highest acceptable level of chlorine content in the deposits with respect to corrosion rate.

The use of additives and other co-firing variations should be investigated in an effort to obtain higher efficiency and flexibility in power plant

operation with respect to the amount of biomass combusted. Similar to coal-firing, further work is required to reduced CO and NO_x emissions. Present investigations show that KCl poisons de-NO_x catalysts, so research into alternative catalysts is required.

Materials problems and ash deposition are also observed in the colder parts of the boiler such as the economiser and preheater – better solutions are required here. Economic utilisation of ash by-products with the many variations of fuels used is also important for the overall cost effectiveness of the plant.