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Co-firing of coal and biomass: Development of a conceptual model for ash formation prediction

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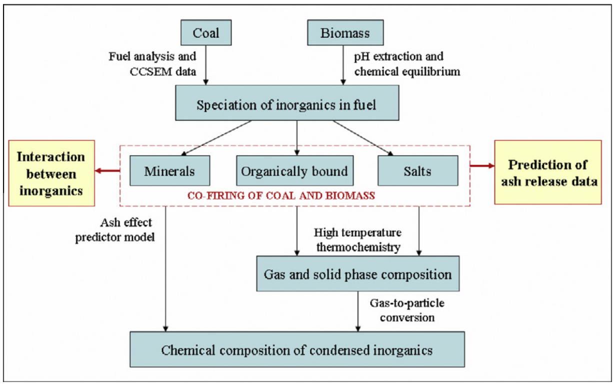
HIGHLIGHTS

- Developed conceptual model to predict release of inorganics for combustion of blends.
- An advanced analytical method was developed to determine the speciation of biomass.
- Determined inorganic speciation using pH-controlled extraction analysis for biomass.
- Observed higher heterogeneous condensation (than homogenous) on boiler surfaces.
- Studies show 'buffering' effect on biomass alkali metals and its release.

GRAPHICAL ABSTRACT

The conceptual model developed for ash formation during co-firing of coal and biomass has been divided into several sections (as shown below). Ash formation depends upon the possibility and extent of fragmentation or coalescence of the coal particle. The same holds true for the behaviour of the mineral matter in a biomass during combustion. However, the ash formation behaviour for the volatile and more reactive inorganics within biomass is completely different. The work in the proposed model focuses on the vaporised and organically bound inorganics within biomass. Firstly, for biomass, it is vital to have detailed knowledge of the chemical speciation of the inorganics in the fuel. Secondly, high temperature chemical equilibrium calculations are used to predict the gas phase of biomass, both in the radiant and convective section of a boiler. The results of the biomass speciation are taken as the input for this high temperature modelling and the model provides further knowledge about the composition and phases of ash released during combustion and the interaction between ash-forming elements of biomass with coal. Conceptual model showing the co-firing advisory tool functions.



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ABSTRACT

The co-firing technology of biomass with coal has been implemented to enhance the usage of biomass in power generation, thus reducing the release of greenhouse gas emissions. This study deals with the fireside issues, namely ash-related issues that arise during co-firing of coal and biomass. Ash release from biomass can lead to ash deposition problems such as fouling and slagging on surfaces of power generation boilers. The scope of this paper includes the development of a conceptual model that predicts the

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chemical composition of inorganics in coal and biomass and its release behaviour when combusted. An advanced analytical method was developed and introduced in this work to determine the speciation of biomass. The method known as pH-controlled extraction analysis was used to determine the inorganic speciation in three biomass samples, namely wood chips, wood bark and straw. The speciation of biomass and coal was used as an input to the model to predict the behaviour and release of ash. It was found that the main minerals species released as gas phases during the combustion of biomass are KCl, NaCl, K_2SO_4 and Na_2SO_4. Gas-to-particle formation calculations for such minerals were carried out to determine the chemical composition of coal and biomass when cooling takes place in the boiler. It was found that the possibility of heterogeneous condensation occurring on the heat exchange surface of boilers is much higher than homogeneous condensation. Preliminary study of interaction between coal and biomass during ash formation showed that Al, Si and S elements in coal may have a 'buffering' effect on biomass alkali metals, thus reducing the release of alkali-gases that can cause deposition and corrosion issues during co-firing. The results obtained in this work can be used in future work to determine the ash deposition of coal and biomass in boilers.

1. Objective

Co-firing biomass with coal is a short term option to reduce greenhouse-gas emissions from existing coal-fired boilers used in power generation. Combusting biomass, a renewable and sustainable energy source with coal in coal-fired boilers, is a practical approach to partial replacement of fossil fuel for power generation. Furthermore combusting biomass in conventional pulverised fuel (pf) fired power plants is an economical option to maximise the use of existing coal-fired boilers. Biomass fuels are considered environmentally friendly as biomass consumes the same amount of CO_2 from the atmosphere during growth as is released during its combustion [1]. Large amounts of wood and other biomass residues remain unused so far and could possibly be made available for use as a source of energy [2]. Although co-firing of biomass and coal represents a cheaper and low risk sustainable energy option, technical issues associated with co-firing, namely difficulty in fuel handling and storage, decrease in overall combustion efficiency, ash deposition concerns, pollutant emissions, and carbon burnout still need to be resolved. However, the main focus in this work is on the fireside issues, as the focal problem during biomass combustion is the high alkali content of its ash. The high alkali content can significantly worsen ash fouling and slagging, reducing the heat transfer in the furnace and convective surfaces of a boiler [3–6].

The aim of this investigation is to develop a tool to improve the understanding of ash behaviour and gaseous emissions during the co-firing of both fuels. The scope of this paper includes the study of ash-related issues during co-firing of biomass with coal, with emphasis given on development of a conceptual model for co-firing. Numerous models and indices are commercially available to predict ash formation for coal combustion. However, these traditional empirical indices used for coals are insufficient for predicting ash deposition in biomass fuels. Coal based indices do not take into account the heterogenous nature of biomass and its mechanisms. In addition, interaction occurs between coal and biomass when the fuels are fired together, leading to inaccurate predictions if available coal indices were used instead [3]. The Energy Research Centre of Netherlands (ECN) has carried out numerous investigations on the impact of biomass co-firing on fouling using a lab scale combustion simulator (LCS) to simulate an actual pf combustion process [7–9]. It was also observed that fouling problems caused during biomass combustion occurred mainly through alkali species that form a sticky deposit layer. Therefore, the scope of this paper is to look at developing a prediction model capable of determining the ash formation that occurs during co-firing of coal and biomass. With further improvement beyond the scope of this paper, the model can be used to provide technical advice to organisations that implement biomass feedstock in coal fired boilers.

2. Ash formation during coal combustion

Besides organic matter, between 5 wt% and 30 wt% of pulverised coal consists of inorganic matter. The volatile organic matter is vaporised with the gases when the heating process begins, which is followed by the burning of char. The incombustible inorganic matter in coal consists of discrete mineral grains and organically bound inorganic matter that form ash after combustion. There are more than 100 types of mineral grains that can be found in coal and some of the major ones are quartz, clay minerals like kaolinite, carbonates like calcites and sulfides such as pyrites. The minerals exist in several forms such as discrete mineral grains, flakes or different-shaped in combined form [3]. These minerals exist either within the coal matrix known as included minerals or outside the coal matrix and are called excluded minerals [10]. The organically associated inorganic matter is mainly alkali and alkaline matter bonded with the oxygen functional groups in coal. This material however is a very small fraction of inorganics in high rank coals and are often ignored in the study of ash prediction models [10–12]. Fig. 1 illustrates the association of the organic and inorganic materials observed in a coal particle.

Ash formation in coal combustion occurs mainly from fragmentation and coalescence of the mineral matter in the coal. However it is noted by researchers that a very small percentage (typically 1 wt%) of ash in coal is formed from vaporisation of the inorganic matter present in the coal [13]. This reaction occurs mainly from vaporisation of fine mineral particles, vaporisation of refractory oxides and the vaporisation of organically bound matter during devolatilization and char burnout [14]. The released material then nucleates homogeneously to form aerosols or condense with other

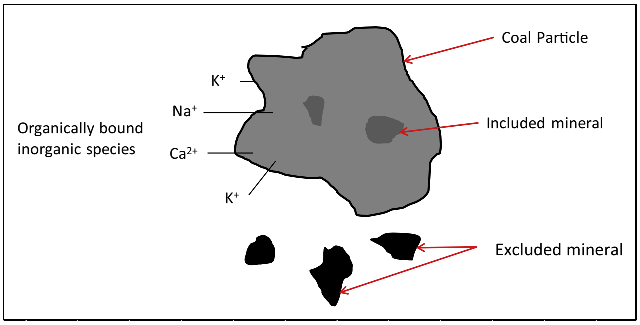

Fig. 1. Organic and inorganic matters in a coal particle.