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Quality of deposits during grate combustion of corn stover and wood chip blends

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HIGHLIGHTS

- ▶ New data on Cl deposition and alkali chlorides formation during corn stover firing.
- ▶ Corn stover was found to be corrosive to power plant superheaters at grate combustion conditions.
- ▶ Problem solution concept must be developed to ensure safe burning of corn stover in power plants.

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ABSTRACT

There is need to increase efficiency of electricity production in grate combustion (GC). This will lead, however, to higher steam temperatures and make superheaters more susceptible to corrosion. Corn stover (CS) is one of the most abundant agro-biomass residues available to energy production on a global scale and GC power plants are best suited to its combustion. The focus in this study was the quality of deposits during GC of CS blended with wood chips. CS is a difficult fuel at least due to its high chlorine content (up to 1 wt%). After a thorough fuel analysis (also with wheat straw, for comparison), combustion tests were conducted with a 100 kW grate reactor, where gas temperature versus residence time can resemble that in a full scale GC power plant furnace. Flue gas composition, alkali chloride mass flow, mass deposition, and deposition of chlorine and other key elements at critical positions of two superheater simulators were measured. Corrosivity of deposit, if estimated only from the maximum chlorine concentration found in deposits, reached maximum already with 20 ± 3% portion of CS on energy basis (which was the lowest portion of CS in the tests). However, further increase of the portion of CS in the blend was found to increase the overall mass deposition and also Cl mass deposition through this way. Because corrosion reactions consume elemental chlorine, the corrosivity (metal loss) at superheater area can increase as a function of CS portion in range >20% CS. Ash problems found on the grate were mostly due to the high mineral content in CS. These minerals originated mainly from the soil (during the harvesting stage), which led to higher ash melting temperatures compared to wheat straw ash.

1. Introduction

1.1. Potential and challenges of agro-biomass in combustion

Large quantities of agro-biomass (like straws) remain unutilised globally. In many countries a large portion of electricity is produced with fossil fuels while agro-biomass is available. Replacing fossil fuels partly with agro-biomass in power production might reduce CO_2 emissions significantly.

The most important in-furnace problems which can appear during power production from agro-biomass are:

(a) Superheater fouling and high temperature Cl corrosion, possible in all common power plant combustion techniques: pulverised fuel (PF), fluidised bed (FB) and grate combustion (GC) [1–15].
(b) Ash slagging due to low melting chemical compounds also common to all combustion methods. FB combustion is based on the use of sand to stabilise combustion and to maximise heat transfer to the fuel. However, the presence of sand may sometimes enhance ash slagging leading to a phenomenon called sand bed agglomeration [16–27].

Furnace conditions, such as temperature distribution (T.D.), can vary greatly between different combustion methods and T.D. affects furnace combustion chemistry, such as the formation of alkali chlorides, their sulphation, and the binding of active sulphur by calcium compounds. Among the combustion methods discussed

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here, furnace temperature is lowest and temperature distribution most even in circulating fluidised bed (CFB) combustion, where circulating sand prevents temperature peaking in the furnace. Temperature peaking is more pronounced in bubbling bed (BFB) combustion, where the sand does not circulate. GC can produce highest temperature peaks in the furnace. Superheater temperatures can be adjusted to the same value in all these combustion methods, although very effective GC power plants (with steam temperatures 540–560 °C) are not yet on the market.

1.2. High temperature superheater corrosion: problem determination

High temperature chlorine corrosion of superheaters during biomass combustion is due to chlorine deposition followed by reactions between chlorine and metal. Such corrosion consumes elemental Cl in a chain reaction which forms iron and chromium oxides through their chlorides [1] and is possible at high steam temperatures [1,12,13]. One can put a rough risk limit (for example $T_{steam} = 420$ °C), but the real limit is dependent on the mass flow of alkali chlorides, gas temperature, alloy composition and temperature, construction and placement of the superheaters.

One method in preventing superheater corrosion is to prevent chlorine deposition [28–30]. Alkalis (K and Na), which are usually present in excess in relation to Cl, play a key role as Cl carriers into the deposits [30–32]. Chlorine forms elemental Cl in the deposit, which reacts with the superheater metal [1]. SO_3 (from fuel-S) and aluminium silicates can prevent or reduce markedly Cl deposition by destroying alkali chlorides (see Eqs. (1) and (2)) before they can condense on the superheater surfaces [28–32]. According to the latest investigations alkalies also may be corrosive [33]. Fig. 1 illustrates alkali chloride condensation on a superheater tube during combustion of agro-biomass.

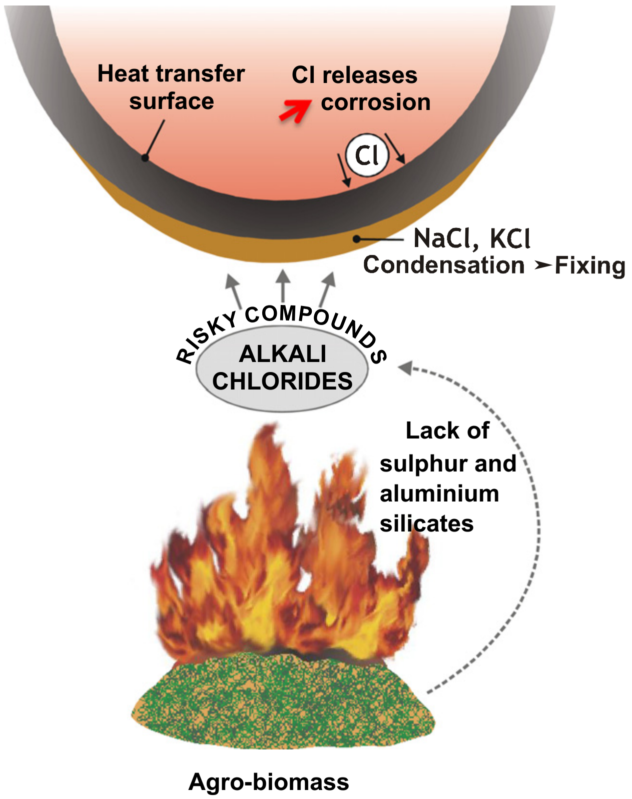

Fig. 1. Chlorine condensation on superheaters during agro-biomass combustion [28].

$$2MCl + SO_3 + H_2O \rightarrow M_2SO_4 + 2HCl \tag{1}$$

$$2MCl + Al_2O_3^*2SiO_2 + H_2O \rightarrow M_2O^*Al_2O_3^*2SiO_2 + 2HCl \tag{2}$$

MCl is KCl or NaCl

Even during combustion of bark with a very low Cl concentration (about 0.02 wt%), and very low measured mass flow of Cl in alkali chlorides (5 mg/Nm^3 6% O_2), Cl concentrations up to 7 wt% were found at one location in the deposit [29]. Even such Cl concentration may lead to corrosion, or at least increasing fouling of superheaters. Blending 7% on energy basis recycled fuel (REF with 0.64 wt% Cl, comparable for example to low-quality straw) with bark increased Cl mass flow strongly in alkali chlorides and Cl deposition [29]. The measured high Cl concentrations in the deposits (15–25 wt% [30]) lead to firm deposits and can cause fast metal loss from the superheaters with high metal temperatures [1,12,13].

The same REF was also co-fired with two different coals and bark. With bark/REF blends (60%/40%), the mass flow of Cl in alkali chlorides was 165 mg/Nm^3. This mass flow of aggressive Cl produced very high concentrations of Cl in the deposits [31]. Co-firing REF with coals decreased alkali chloride concentration by alkali aluminium silicate formation and sulphation and weakened or prevented alkali chloride deposition [31].

1.3. Purpose of this work

The focus in this work was to study the quality of deposits during GC of wood and corn stover (CS) blends. Deposits were collected on rings at metal temperatures simulating superheater conditions. In addition, results of ash behaviour on the grate were presented briefly although they are dependent on grate construction. The superheater study included the following research issues: how does the mixing of CS with wood chips affect the mass flow of Cl in alkali chlorides, overall mass deposition, mass deposition of Cl, and concentration of Cl at various locations of the deposit. Modern sampling and analysis techniques (used in this study and illustrated later) are necessary for this kind of research. Similar studies (with similar alkali chloride sampling and determination and deposit analysis) have not been done at GC conditions.

2. Experimental techniques

2.1. Fuels and their analysis

Spanish wood was received as chips of 15–40 mm in diameter and 2–4 mm in thickness. These chips were combusted as such. Spanish corn stover (CS) was obtained in bales, which were crushed. In addition to these fuels (for combustion tests), Spanish wheat straw was selected for fuel analysis to compare its properties especially to CS. The standard codes of each method used for fuel analysis are shown in Table 1.

2.2. Chemical fractioning (conducted in ENAS OY)

Chemical fractioning has been developed as a useful tool to give more detailed information on the elements in the fuel other than just their concentration [34,35]. The sample was ground using a 1 mm sieve and homogenised. The fractioning was conducted in three phases: water, acetate and acid extraction.

Water extraction: 5 g of ground sample was put in a 250 ml plastic bottle and 100 ml of distilled water was added. The mixture was shaken for 16 h (overnight), centrifuged and filtrated with suction. The sediment was washed with two portions of distilled water. The filtrate was put into a 250 ml bottle and water was added up to 250 ml.