



Investigation of deposit formation and its characterization for a pulverized bituminous coal power plant



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ABSTRACT

Fouling and slagging depend upon the boiler and firing system design, operational parameters and fuel properties. Release of inorganic compounds during combustion and their transformation into critical gaseous species, aerosols and ash particles may substantially affect the boiler efficiency and availability, due to the formation of fireside deposits. The composition of the mineral matter in three bituminous coals and the associated deposits formed at the inlet of the superheater level in a 730 MW_{th} pulverized fuel boiler are discussed in this paper. A cooled probe was used to investigate the initial layer of the deposits while an uncooled probe was used to investigate the outer layer. In all initial layers, spherical (formerly molten) iron-rich particles, likely derived from pyrite were observed. Moreover, particles in the initial layers and mineral phases of the coal samples were determined quantitatively. Based on these analyses thermo-chemical equilibrium calculations were performed using the FACT-Sage simulation software to identify the effect of reducing and oxidizing flue gas atmospheres on the ash melting behavior and to assess their importance on the build-up of the initial deposit layers. The results of this work indicate that the deposition of an ash particle is strongly influenced by the particle's history. Besides its composition, in particular, temperature, and the atmosphere that a particle passes through have a significant influence on the mineral transformation and the adhesion of the particle.

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1. Introduction and background

The ash from coal combustion has been a long-standing problem for the power generation industry, which has been under investigation for over a hundred years [1–4]. Deposits are formed by several different transport mechanisms described in the literature, such as diffusion, thermophoresis, condensation, inertial impact and chemical reactions [2,3]. A particle in the flue gas will adhere to the tube or the deposit surface if either the particle or the surface is “sticky” enough to overcome the kinetic energy of the incoming particle, and prevent it from rebounding away from that surface. The ash deposits in coal-fired furnaces are generally classified into two separate modes of occurrence: slagging and fouling deposits. Slagging occurs in the high temperature radiant sections of the boiler and is usually associated with some degree of melting of the ash. Fouling occurs in the lower temperature convective sections of the boiler, such as the superheater, reheater and economizer regions. More details on fouling and slagging can be found in the literature [2–5].

In order to assess the deposits on superheater tube surfaces in fossil-fuel fired power plants, initial and outer deposit layers are investigated.

The initial ash layer is, according to literature, conventionally understood as a build-up of condensed alkali salts, which form a sticky layer to capture impacting ash particles that are not molten. In general, the initial layer is rich in small particles that have high levels of flame-volatilized species such as sodium and sulfur. It is dominated by alkali sulfates, chlorides and simple oxides such as CaO, MgO, FeO, Fe₂O₃, and Fe₃O₄ [6,7]. However Creelman et al. [8] reported based on detailed mineralogical investigations very little evidence to support the conventional notions of adhesion. They also noted that the suggested chemistry is questionable. The results of this work support the observations of Creelman et al. [8], who found iron that was derived from the pyrite in the initial deposit layers. Pyrite is thermally instable and depending on the mode of occurrence may react in the furnace environment to form inactive iron oxide (e.g. hematite) particles. It may also react with clay minerals to form molten iron-alumino-silicates and become a thermally active component [9]. Iron-based minerals have been identified to contribute to ash deposition and slagging. Reactions and changes in pyrite chemistry vary considerably on combustion conditions. The ash formation mechanisms of the pyrite mineral and the influences of reducing conditions on pyrite transformation have been discussed in previous studies [10–20]. McLennan et al. [11] reported that in coal combustion excluded pyrite decomposes to pyrrhotite and then partially oxidizes from the surface inward to produce a molten FeO–FeS phase (melting point approx. 1080 °C). This melt then subsequently is oxidized to magnetite and hematite depending on the availability of oxygen in the

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combustion atmosphere. Therefore, this process may be delayed by the oxygen consumption of the char combustion. According to McLennan et al. [11] included pyrite that contacts with aluminosilicate minerals will form two-phase FeS/Fe-glass ash particles. These particles may also further incorporate iron into the glass after the FeS phase is oxidized. The delay in glass formation may be accentuated by the associated reducing conditions.

Due to the stickiness of the initial deposition layer, particles arriving at the tube surface adhere and ash deposits build up. When the temperature at the outer deposit surface is high enough for some ash particles to be molten, even unmolten particles may adhere to the deposit surface that is rendered sticky by molten ash particles. As the deposit grows, larger aluminum and silicon rich particles are captured so that the deposit may approach the bulk composition of the coal ash [5,21]. Knowledge of how and why the initial deposit layers are formed is important for a better understanding of the overall deposit formation process. Therefore, the deposition behavior of three different bituminous coals (Calentur, Pittsburgh and Peabody) in a 730 MW_{th} boiler was investigated in different experimental campaigns. The main objective of this investigation was the initial but also outer deposit layers of samples taken at the inlet of the superheater zone in the pulverized fuel boiler during combustion of each of the three coals.

2. Experimental section

2.1. The pulverized fuel power plant

Fig. 1 shows the boiler of the power plant in which the experiments were performed. The cross-sectional area of the boiler is about 12 m × 12 m and the height is 67.5 m [22].

The boiler is designed with three burner levels and air staged low NO_x combustion. As a result there are two combustion zones in the boiler: A reducing zone and an oxidizing zone. For air-staged low NO_x combustion, pulverized coal and combustion air are injected into the lower regions of the boiler with stoichiometry less than one (i.e., reducing conditions) [23,24]. This leads to an initial combustion zone with a reducing atmosphere in the lower regions of the boiler, with a typical particle residence time of 1–2 s [25,26]. After this, burnout air is added

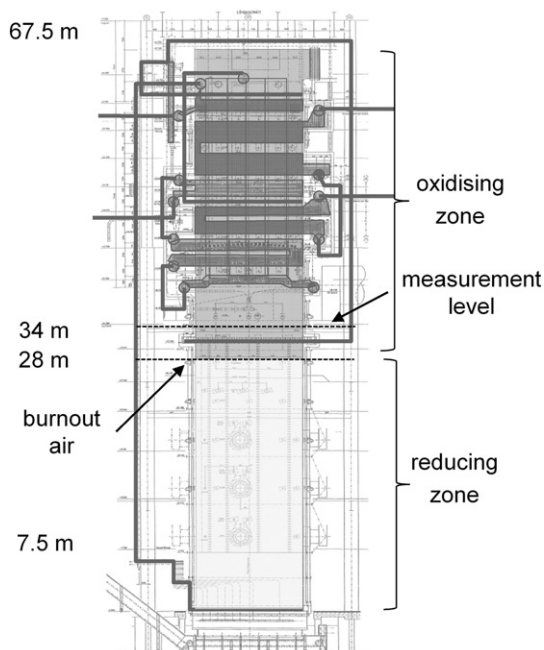


Fig. 1. Scheme of the power plant 730 MW_{th} [22].

to complete the combustion in the upper regions of the boiler (oxidizing secondary zone).

2.2. Deposit and fly ash sampling

A number of different sampling probes were used to sample fly ashes and deposits at the inlet of the superheater. All subsequent samples were taken from one port at level 34 m at a distance of 400 mm from the inner boiler wall (see Fig. 1). Fly ash was sampled from the furnace using a cooled suction probe. Fly ashes are separated from the sample gas with a cyclone and a filter. Two types of probes were used to investigate the growth and development of the deposits. Deposits were sampled using uncooled (outer layer) and cooled (initial layer) deposit sampling probes. In the present tests, the temperature of the initial layer deposition probes' surface was set to approx. 480–690 °C. Gas composition and temperature profile measurements were performed at the same location at which deposits were sampled. The boundary conditions during initial layer depositions sampling are given in Table 1. For the Pittsburgh coal also corrosion tests were carried out as a part of another study. Therefore, the Pittsburgh deposit sample was exposed for a longer time (231 h) than the Calentur and Peabody samples (3–4 h). The minimum and the maximum measured values are given for flue gas compositions and the temperatures. Due to the limited time available for the measurement campaign the gas composition were not determined for the Peabody coal. However, for this coal it can be assumed that there was a similar gas atmosphere (oxidizing atmosphere) as for both the other coals. The sampling conditions for the uncooled deposit (outer layer) are given in Table 2. The uncooled deposits were sampled at the same place as the initial layer deposits, and therefore the gas atmospheres were comparable to the ones given in Table 1. The temperatures of the uncooled deposition probes surface were equal to the flue gas temperature.

After sampling the deposits they were embedded in an epoxy resin and afterwards grinded and polished as described in [27]. The polished samples were analyzed by scanning electron microscopy (SEM). The electron microscopy was performed with a CAMECA SX100 electron microscope. The apparatus is equipped with five wavelength-dispersive spectrometers WDX and a conventional EDX system. The up-wind parts of the initial deposit layers were analyzed to determine the chemical composition, the morphology and the particle size of the deposits.

2.3. Coal characterization

Fuels were sampled after milling in the power plant. The fuel samples were analyzed by different analytical techniques according to the DIN standards presented in Table 3.

2.4. Analyses of the mineral matter in the coals

In order to determine the mineral matter in the coals, samples of each coal were ground to fine powder and subjected to low-temperature oxygen-plasma ashing. The percentage of low-temperature ash was

Table 1
Sampling conditions of the cooled deposits (initial layer).

Coal	Cooled deposits (investigation of the initial layer)		
	Pittsburgh	Calentur	Peabody
Exposed time [h]	231	3	4
Flue gas temperature	990–1111 °C	1030–1065 °C	~990–1065 °C
Probe temperature	690 °C	480 °C	480 °C
Material of the tube	Ni-basis alloy 740	X10CrMoVNb 9–1.	X10CrMoVNb 9–1.
O ₂ [vol.%, dry]	2.7–3.6	1.2–2.8	–
CO ₂ [vol.%, dry]	14.8–15.8	16.2–17.5	–
CO [ppm]	41–665	198–1043	–
NO [ppm]	168–197	106–120	–
SO ₂ [ppm]	592–625	523–610	–

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