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A temperature-history based model for the sticking probability of impacting pulverized coal ash particles

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ABSTRACT

Several investigations have shown that the differences between deposits obtained in oxy-firing and air-firing of coal mainly are due to differences in the flame temperature. Consequently, deposit rate predictions not taking the in-flight history into account are unlikely to be successful. In this paper, a model for predicting the deposit formation propensity of pulverized coal in oxy-fuel and air combustion due to the inertial impaction mechanism is developed and tested. The model builds on the use of viscosity as an indicator of the sticking probability. The composition and amount of the amorphous slag phase in the coal ash are calculated assuming thermodynamic equilibrium. Further, it is assumed that the maximum temperature the ash particle has experienced will control the composition and amount of the amorphous slag phase. As the ash particle impacts the probability to stick is estimated using the viscosity of this melt composition, but with the temperature of particle temperature at the moment of impaction. In the equilibrium calculation no material exchange with the gas phase is assumed. This assumption is based on X-ray diffraction (XRD) investigations of coal ash samples produced in a lab-scale burner simulating oxy-fuel and air combustion. The XRD showed that there was no significant impact on the mineralogy of the coal ash caused by the gas atmosphere. The probability of an ash particle to stick as a function of maximum experienced temperature and impact temperature was evaluated for three coals. For one of the coals a CFD study on particle deposit is done for a 300 kW_{th} test facility.

1. Introduction

Deposit build up in coal fired boilers involves a large number of physical processes. The deposit mechanism depends on the ash particle properties, including, size, velocity, composition and temperature. Fully molten ash particles will easily collect on a cool wall. On the other hand, a large flux of solid particles with a high momentum will have an eroding effect and may keep the surface clean. In addition to the ash particle properties, also the properties of the surface may be equally important. A molten surface acts as an efficient collector, but may also have such properties that the deposit will reach an equilibrium thickness. In a boiler the operational mode and operational history will influence the deposit build up: soot blowers will modify the deposit and the composition of deposits on the wall depends on previous fired coal qualities and load variations. Even the unlikely event of starting from a boiler with clean walls and firing using the same fuel will provide a challenge to a modeler, although some studies in this direction have been presented [3,7,15].

In the literature a number of models aimed at predicting the deposit propensity of coal ash can be found. Traditional indices and deposit models have been summarized by Wang and Harb [15]. In the present study, the focus is on models applicable to CFD and not to empirical indices and ash fusion tests, although these also can be combined with data from CFD modeling of boilers. Walsh et al. [14] developed a model for deposit build up of coal ash particles on heat exchanger tubes. They assumed that the sticking probability of the molten or super-cooled ash particles is inversely proportional to the viscosity. This is an assumption now commonly used. In their study Walsh et al. [14] used an empirical model to calculate the viscosity using analyzed furnace exit ash composition as input. When modeling the deposit build up of biomass ash, the melt fraction is frequently utilized. Typically, the melt that is formed has a low viscosity. For such fuels it is often assumed that ash particles will stick if their melt fraction exceeds a critical value [2,9]. For straw, a fuel forming a more viscous ash, Zhou et al. [16] used similar approach, assuming a linear relationship between the melt fraction and the probability to stick in the range 0.1 to 0.7.

The use of an equilibrium approach to assess the behavior of coal ash has been used in several studies. Harb et al. [4] evaluated this approach for a number of coal ashes using observed slagging propensities and

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Table 1
Ash compositions of laboratory coal ash samples.

Coal	Na_2O, $\%_{wt.}$	MgO, $\%_{wt.}$	Al_2O_3, $\%_{wt.}$	SiO_2, $\%_{wt.}$	P_2O_5, $\%_{wt.}$	SO_3, $\%_{wt.}$	K_2O, $\%_{wt.}$	CaO, $\%_{wt.}$	TiO_2, $\%_{wt.}$	FeO, $\%_{wt.}$
SAC	–	–	31.3	49.9	2.5	3.3	0.9	5.7	4.5	2.0
Sebuku	0.8	1.5	32.2	38.9	2.3	6.2	0.6	5.6	4.3	7.4
P. no. 8	0.7	0.6	30.7	53.3	0.5	1.5	2.8	1.7	2.9	5.3

calculated melt fractions. They found that using equilibrium calculations based on models using ideal solutions of complex species performed poorly for silica rich ashes. They recommended the use of stoichiometric methods, which use a simple species set and account for the formation of complex species and non-ideal mixing with activity corrections determined from experimental data for such ashes. Jak [6] used the thermodynamic computer package F*A*C*T to calculate coal ash fusion temperatures. He found good agreement between the flow temperature obtained from ash fusion tests and the calculated melt fraction. Thompson [12] used another thermodynamic computer package, MTDATA, to compare predicted ash melting profiles and measure flow temperatures for 30 different coals. For all but two coals the observed flow temperature coincided with 75–100% mass of mineral content in the melt.

Coal ash deposits in oxy-fired boilers are expected to differ from those of air fired. The change can be caused by the composition of the gases and by changes in temperature. To the authors' knowledge no model exists that can account for these changes. In this study a model, which takes the changes to the temperature field into account, is developed for predicting the probability of an ash particle to deposit on a heat transfer surface. The model builds on the viscosity based sticking probability assumption put forth by Walsh et al. [14]. Thermodynamic equilibrium modeling is utilized in the prediction of coal ash viscosity. The model is only accounting for properties of the ash particle. In a boiler, also the properties of the surface the ash particle is impacting will be of great importance. A non-molten particle that would not stick to a clean boiler wall may well stick to a slagging wall. However, including the wall behavior introduces a whole new dimension to the problem, as the deposits are a result of the boiler operation history.

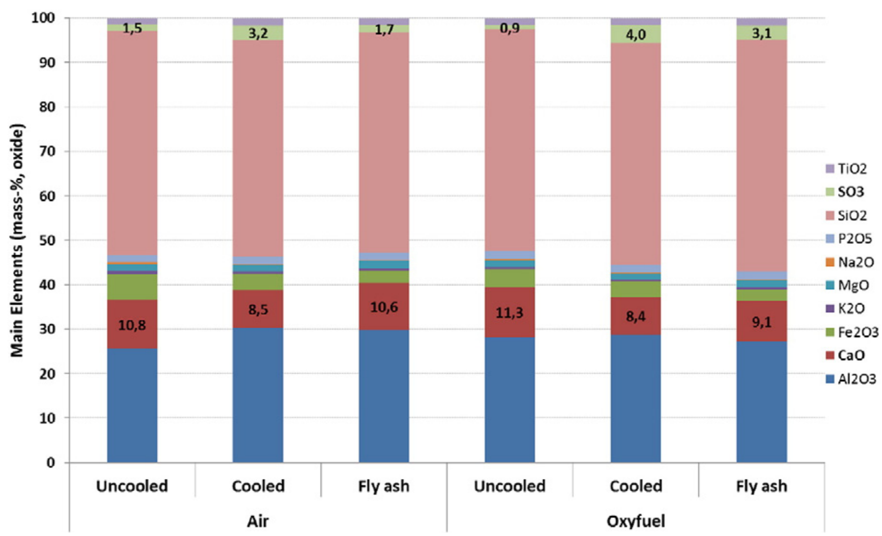

Fig. 1. Main elements as oxides in the South African coal ash collected in three different ways during air firing and oxy firing.

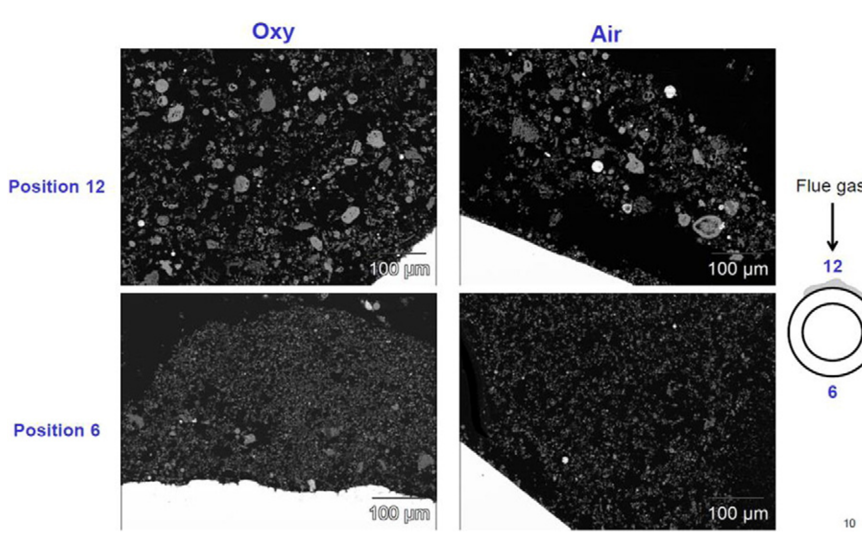

Fig. 2. SEM picture of the ash deposit collected with the cooled probe. Position 12 refers to the windward side, position 6 to the lee side.