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Ash formation and deposition in coal and biomass fired combustion systems: Progress and challenges in the field of ash particle sticking and rebound behavior

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ABSTRACT

The purpose of this paper is to review the present knowledge on ash formation, ash particle transport and deposition during solid fuel combustion, with emphasis on particle sticking and rebound behavior. A substantial part of the fuel can be inorganic, forming inorganic vapors and ash particles. The impaction of solid, molten or partially molten particles on surfaces is dependent on the particle and surface characteristics. For instance, a particulate deposit might capture incoming particles or be removed due to erosion, while a molten layer will collect all impacting particles, no matter if they are sticky or not. The main properties affecting the particle stickiness are the viscosity and surface tension for silicate-rich ashes. On the contrary, the stickiness of salt-rich ashes – typical for herbaceous biomass and wood- or waste-based fuels – is often described using the liquid melt fraction. Furthermore, the particle kinetic energy and the angle of impaction, are crucial parameters. If all kinetic energy is dissipated during the impact, the particle will remain on the surface. This review presents an overview of major ash forming elements found in biomass and coal, and discusses the heterogeneity of particles' inorganic composition. Ash transport and deposition mechanisms as well as their mathematical description are given and discussed, together with composition- and temperature-depended models for the estimation of ash particle and deposit properties. These properties are essential in order to describe the particle sticking and rebound behavior.

Ash particle sticking and rebound criteria can be divided into three main groups, based on either: (1) the particle melt fraction, (2) the particle viscosity, or (3) the energy dissipation of a particle, upon impaction. Sticking criteria are presented, their required parameters are discussed and typical particle and surface properties found in combustion systems, are summarized. Eight different sticking criteria are implemented in a computational fluid dynamics code and computations are compared against measurements from an entrained flow reactor. Uniform sized soda-lime glass particles are applied instead of inhomogeneous fly ash particles, since soda-lime glass is known to behave similar to coal fly ash. Best agreement for the deposition rates on a clean tube is achieved using a criterion based on the work of Srinivasachar et al. [1]. In this model, the sticking and rebound threshold, is a function of the particle kinetic energy, the angle of impaction, and, the particle viscosity. Particularly, the particle viscosity is confirmed as a key parameter for silicate-rich ashes. It should be calculated using temperature- and composition-dependent correlations, being aware that there is a significant scattering in the results from such models and that the models are often only valid in narrow compositional ranges, and cannot be used outside these. A mechanistic model is used to explain results from glass particle experiments and their dependence on the particle kinetic energy. Therefore, the impaction process is subdivided in four steps, and the energy dissipation of each step is calculated. These theoretical considerations show that the contact angle of a molten droplet with the substrate is of minor importance, and that the majority of depositing particles are dominated by the work of deformation against viscosity, rather than surface tension effects.

This review underlines the importance of the particle viscosity, and its accurate prediction for silicate-rich ashes. The proposed criterion is able to predict the sticking of small, solid particles below 10 μm diameter, as it is often observed in literature. Also, it is crucial to consider the surface structure and stickiness, in order to predict deposition rates in solid fuel-fired systems. Biomass ashes and their stickiness are more difficult, due to a different ash particle chemistry, compared to coal ashes. Salt-rich particles and their stickiness are

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controlled by the amount of liquid phase. Here, a link between the viscosity and amount of liquid phase is a promising approach, and should be addressed in future work. Furthermore, the viscosity of different ash particles – silicate-, salt- or Ca-rich – should preferentially be modeled from the chemical and physical structure instead of an empirical fitting procedure between fuel chemistry and viscosity measurements.

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