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Modelling of ash deposition in biomass boilers: a review

Cai Yongtie[a,b], Yang Wenming[a,b]*, Zheng Zhimin[a,b], Xu Mingchen[a,b], Siah Keng Boon[b,c], Prabakaran Subbaiah[b,c]

[a]*Department of Mechanical Engineering, Faculty of Engineering, National University of Singapore, Singapore 117576, Singapore*
[b]*Sembcorp-NUS Corporate Laboratory, National University of Singapore, Singapore 117576, Singapore*
[c]*Sembcorp Industries Ltd, Singapore 179360, Singapore*

Abstract

The ash deposition process in biomass boilers can induce many ash-related problems. It will reduce the heat transfer in the furnace walls and convective pass tubes and decrease the boiler efficiency and capacity. Previous review work and experience about the ash deposition process was almost focusing on coal-fired utility boiler, providing an extensive summary of knowledge and current developments about ash deposition processes, but few was concentrating on the biomass fuel-derived boiler. Numeral empirical and traditional methods, such as ash fusibility, ash viscosity, and slagging and fouling indices, which are based on the temperature and the chemical compositions, cannot fully predict the complicated ash deposition processes. To understand the nature of ash deposition in biomass boilers, full attention should be paid to the ash deposition processes, including the transformation process of mineral matter in biomass fuels and deposition characteristics. To predict the ash deposition process, some ash deposition models, such as the ash transportation model, the ash formation model, the ash impacting model, the ash sticking model and the ash growth model, should be developed. This paper will give a brief introduction to the traditional methods about the ash deposition. In additional, an extensive state-of-the-art review of the ash deposition in biomass fuel-derived boiler will be presented. Lastly, the comprehensive ash deposition models including the mechanistic models and CFD modelling will be built to address the ash-related issues, which can guide further investigation.

Keywords: biomass; ash deposition; numerical modelling; deposition mechanisms; deposition properties; deposition models

* Corresponding author. Tel.: +65 6516 6481; fax: +65 67791459.
E-mail address: mpeywm@nus.edu.sg

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1. Introduction

Nowadays, renewable energy, like biomass brings substantial benefits, including the economic, social and energy security aspects. Despite its advantages, the challenges and problems occurred during the biomass combustion process cannot be ignored. One of the largest problems is the ash-related problems during the combustion process, called slagging and fouling deposit. These ash-related problems have negative impacts on the boiler, such as reducing the heat exchange and boiler efficiency. [1]

Clearly, the ash deposit process is extremely complicated and it is of great importance to understand the mechanisms of the process. This paper will present an overview of the mechanisms and models of ash deposition that have been developed for coal and biomass combustion systems and propose different predictive tools and techniques for the biomass combustion systems. This will help address the ash-related problems to some extent.

2. Existing characteristic approaches for biomass ash deposit

To understand the ash deposit process, the properties of fuels and ash should be first investigated, including the chemical, mechanical and thermal aspects. (1) **The chemical properties** include the chemical compositions and mineral phases of ash deposit. The chemical composition can be determined by standard analysis techniques, such as Atomic Absorption Spectroscopy (AAS) and Computer Controlled Scanning Electron Microscopy (CCSEM). The mineral phases can be determined by X-Ray Diffraction (XRD) and CCSEM. (2) **The mechanical properties** include several aspects. a) **The porosity** is calculated by the bulk density and true density. This property can be measured by standard test techniques and by Scanning Electron Microscope (TMA) and thermomechanical analysis (TMA). b) **The strength of the deposition** is dependent on the viscous flow sintering of deposit particles. c) **The viscosity of ash deposit** is associated to the internal structure of oxide melt. Some viscosity models has been developed to predict it, including Urbain model, Ribound model, Nicholls & Reid model and Senior & Srinivasachar model.[2] d) **Ash fusibility** is one of the most used parameters to predict the ash behaviour. Several standard methods and procedures are used to perform the ash fusion test (AFT). [3] (3) **The thermal properties** of ash deposit are as follows. i) **The radiative properties** (reflectivity (ρ), emissivity (ε) and absorptivity (α)) are important to characterize ash deposit. The effective radiative properties are determined by the surface temperatures and spectral distributions. ii) **The thermal resistance** to the surfaces through conduction is quantified by the effective thermal conductivity which is dependent on the physical properties, the structure and their thermal conditions.

3. Predictive approaches for ash deposit

Several predictive approaches have been developed to predict the ash deposition process, including the empirical methods, mechanistic methods and advanced computational fluid dynamics (CFD) modeling methods. (1) **Empirical methods**. a) **The ash fusibility** influences ash deposition process. The ash fusion behaviours can be described by a melting curve which can be determined by the Standard Ash Fusion Test. [3] Some characteristic temperatures for the ash deposits are commonly identified to describe the physical behaviours of ash deposition, including T_{15}, T_{70}, T_{cv} and T_{250}. b) **Slagging and Fouling Indices** which are based on the ash fusion temperature or chemical compositions have been developed to quantify the ash deposits. Some empirical correlations have also been developed to predict the deposition tendency, including $R_{b/a}$, R_s, R_m, R_{vs}, R_F, F_u, S_R, Cl^r. [4] (2) **Mechanistic methods**. a) **Comprehensive modeling method**. Several attempts have been made to develop different models which are mechanistic in nature to address ash-related issues. And a great amount of information is available in the following processes, including ash formation process, fluid dynamics and particle transport, deposition growth rate, particle impaction and sticking, heat transfer through ash deposits, deposit structure and the effect of deposition on operation conditions, etc. [1, 4-6] b) **The thermodynamic equilibrium modelling** is a powerful tool to quantify the amount and composition of different phases [6] and to predict the transformation of chemical species. The modelling is based on the minimization of the Gibbs energy of the system.[7] And the thermodynamic equilibrium analysis can be performed by some different kinds of software which focus on the phase diagrams, including ChemApp, ChemSheet and FactSage.[7] (3) **Advanced CFD modeling methods**. The overall modelling of ash deposition process can be incorporated into CFD codes to simulate the deposition process. Several key phenomena are considered into these models, including ash particle