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Numerical investigation on ash deposition on the surface of tube bundle

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Abstract

Ash deposition is a major challenge for boilers fired with coal, biomass as well as other solid fuels. It can cause fouling and slagging along the flow path of flue gas, resulting in significant efficiency drop and safety problem. For these reasons, ash deposition needs to be further studied. Computational Fluid Dynamics (CFD) is an effective tool for predicting ash deposition. But there is still a big space for this technology to improve the prediction accuracy due to the complexity of ash deposition problem. Ash deposition is actually a dynamic process, some important parameters such as surface temperature and the shape of ash deposit will change with the going on of deposition time, which have significant influences on ash deposition. In this paper, an effective tool based on CFD was developed to simulate the process of ash deposition with some sub-models implemented into User Defined Function (UDF) codes. Ash deposition on a bundle of tubes was investigated in the unsteady mode. Both inertia and thermophoresis deposition mechanisms are considered in ash deposition model. Fine particles (<10μm) play an important role at the initial stage of ash deposit formation. It is because that the deposition of these fine particles is largely dependent on the temperature gradient between flue gas and surface of ash deposit. The variation of surface temperature and shape of ash deposit with time were predicted. The differences of deposition properties on the tubes at different positions were found. The modelling results indicate that the proposed method is an effective tool to predict the formation and growth of ash deposit.

Keywords: ash deposition; numerical modeling; fine particle; deposition model;dynamic mesh

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1. Introduction

Numerical simulation method based on computational fluid dynamics (CFD) as an advanced method for predicting ash deposition in the boiler was developing dramatically (Richards, et al. (1993); Huang et al. (1996); Wang and Harb (2002); Tomeczek and Wacławiak (2009)). To improve the accuracy of simulating results, it is necessary to develop new ash deposition models taking these factors into consideration. Ash deposition model is a criterion which is used to judge whether a particle will deposit on the surface or not when it impacts this surface. For these particles in the molten or half molten state under high temperature condition, the viscosity model for ash deposition proposed by Walsh et al. (Walsh et al. (1990)) is generally used. Due to its simply formula, this model has been widely used in simulating fouling and slagging in pulverized coal combustion boiler (Huang et al. (1996); Strandström, et al. (2007)). However, this model only considers chemical composition and temperature of ash particles but ignoring several important factors such as the velocity of ash particle and surface temperature of deposition surface. Therefore, the accuracy of this model is limited. Meanwhile, it should be noted that ash deposition is a dynamic process but currently few ash deposition models considering the variations of both surface temperature and shape of ash deposit with deposition time.

In this paper, both inertia impact and thermophoresis deposition mechanisms were considered for ash deposition. A new ash deposition model for inertia impact mechanism based on the viscosity model was proposed. Dynamic mesh technology in CFD was applied to simulate the growth of ash deposit with the variations of the surface temperature and shape of ash deposit on the surfaces of bundle tubes. An effective method based on CFD was developed to predict ash deposition on bundle tubes. It will help to design heater exchangers and boiler.

2. Model and method

2.1. Ash Deposition Model

A revised ash deposition model was developed based on the previous model proposed by Walsh et al. (Walsh et al. (1990)). This model considers the effect of surface temperature of ash deposit on ash deposition. It is assumed that when the surface temperature of ash deposit is lower than the temperature T_l, the ash sticking probability only depends on the temperature of ash particles. However, when the surface temperature increases up to one value exceeding the temperature T_l, the influence of surface temperature of ash deposit on ash deposition starts to work and the sticking probability of ash particle will increase linearly with the increase of surface temperature of ash deposit. When the surface temperature of ash deposit is higher than the temperature T_h, it means the surface of ash deposit has a very high stickiness so that whatever impacting particles on this surface will be captured, and thereby the sticking probability is one. It is described in the following expression:

$$\eta = \begin{cases} \dfrac{\mu_{ref}}{\mu_p}, & T_s \le T_l \text{ and } \mu_p > \mu_{ref} \\ \dfrac{\mu_{ref}}{\mu_p} + (1.0 - \dfrac{\mu_{ref}}{\mu_p}) \cdot (T_s - T_l) / (T_h - T_l), & T_l < T_s < T_h \text{ and } \mu_p > \mu_{ref} \\ 1, T_s \ge T_h \text{ or } \mu_p \le \mu_{ref} \end{cases} \tag{1}$$

Where η is the sticking probability of ash particle; μ_p refers to the viscosity of ash particle; μ_{ref} is the referred viscosity T_l and T_h are the critical low and high temperatures, respectively.

It was reported that low melting compounds could appear at the surface temperature of 773-873 K for Zhundong coal ash which is easy to bring slagging and fouling problem with high contents of alkali metals compounds ((Liu, 2014)). Therefore, temperature T_l is chosen to be 773 K. T_h is chosen to be the deformation temperature (DT) of bulk ash, here T_h is 1473K. Except inertial impaction as a dominant mechanism, the thermophoresis force is also considered in this study. The expression of the thermophoresis force proposed by Talbot et al.(Talbot et al. (1980)) was used here.