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Effects of coal blending on the reduction of PM_{10} during high-temperature combustion 2. A coalescence-fragmentation model

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ABSTRACT

A coalescence-fragmentation model has been developed to predict the behaviors of coal mineral particles during the combustion of pulverized bituminous coals or coal blends. Based on the computer-controlled scanning electron microscope (CCSEM) characterization of coal minerals, the particle size distributions (PSDs) and mineral species of ash particles can be simulated. In particular, the interactions among excluded minerals (mainly referring to the excluded Ca-bearing-species and Fe-bearing-species) and included minerals are accounted for in this model. The PSDs and the mineral species of ash particles are derived from the coalescence and fragmentation of coal mineral particles. Based on this proposed model, both of the predicted PSDs and the mineral species of ash particles are in good agreement with their corresponding experimentally measured values. And the comparisons further demonstrate that the combined effects of coalescence of included minerals and fragmentation of excluded minerals have direct impacts on the ash-forming process. In addition, for the coals rich in excluded Ca- and/or Fe-bearing-species, the interactions among included minerals and excluded minerals are another important mechanism governing ash formation for high-rank coals.

1. Introduction

Particulate matter with the aerodynamic diameter less than 10 μm (PM_{10}) released from coal combustion causes air pollution problems and severe adverse health effects. This is especially prevalent in the developing countries where coal is the dominant fuel for the nation's industries [1–3]. In order to improve the efficiency of coal utilization, and to reduce emitted pollutants, coal blending has been developed and applied in coal-fired plants [4–8]. Although coal blending is used by many coal-fired power plants, the emission behavior of a coal blend is not a linear function of the emission behavior of its constituents. As a result, the combustion results of blending coals are difficult to be predicted, and further experimental and theoretical work on blended coal combustion is required to gain a better understanding of the underlying processes involved [5,9–11].

Mathematical models of ash formation mechanisms have been developed to predict ash-forming process [4,12,13]. These models are nearly developed based on CCSEM data. They include: (i) no coalescence model, which assumes that each mineral grain in the coal particles forms one ash particle [13], (ii) partial coalescence model, which assumes that all the mineral grains in one coal particle forms some ash particles [4,12], and (iii) full coalescence model, which assumes that all the mineral grains in one coal particle forms one ash particle [13]. Excluded minerals are assumed to directly transfer into ash particles or fragment [4,12–14]. Furthermore, all existing models suppose that no interactions occur among included and excluded minerals during ash formation. However, the interactions among excluded Ca and/or Fe species and included aluminosilicates have been demonstrated by the combustion of coals and coal density separations in our previous study [15]. In particular, for the coals with high amounts of excluded Ca- and/or Fe-bearing-species, interactions among the excluded minerals and the included minerals have an obvious impact on ash formation [15,16]. It is evident that the existing ash formation models are not suitable for simulating these experimental results. Therefore, the development of a model, which considers the interactions among included and excluded minerals, is necessary.

In order to further investigate the interactions among excluded Ca- and/or Fe-bearing-species and included minerals, two coals with different excluded Ca-bearing-species were blended and combusted, whose experimental results have been published in the previous paper [16]. In this study, we mainly present a CCSEM-based model for ash formation, where the interactions among excluded minerals and included are considered, and it is suitable to predict the ash-forming process during the combustion of

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high-rank single or blended coals. The experimental combustion results published in the previous paper are used as the reference data [16]. The CCSEM characterization of coal minerals, together with the bulk ash content of coals, serves as the input of this model. The detailed description of the model has been provided in terms of transformations of included minerals or excludes minerals. In addition, the interactions among excluded Ca- and/or Fe-bearing-species are also considered. The predicted PSDs and mineral species of ash particles are compared with their corresponding experimentally measured results. Finally, the impacts of interactions among excluded minerals and included minerals on ash formation are discussed.

2. Description of the coalescence-fragmentation model

2.1. Input data for this model-CCSEM characterization of coal minerals

CCSEM data of coal minerals are used as the primary input of this model. Approximately 4000 mineral particles in each coal are determined at three different magnifications (150×, 250×, 800×) [16–18]. The determined results, including PSDs of mineral grains, mineral species, and associations of each mineral grain with the particles of coals A and B, are used as the primary input of the model [16]. With respect to coal blends, CCSEM data of raw coals A and B will be blended based on the desired blending weight ratio (coal A:coal B = 5:95, 10:90, 20:80, 30:70, 40:60 or 60:40), and then the blended CCSEM data are used as the input data of the corresponding coal blend, shown as Fig. 1.

2.2. Coalescence-fragmentation model

Fig. 1 also indicates the main calculation diagram of the coalescence-fragmentation model developed in the current study. This model mainly consists of three parts, including (a) transformations of included minerals, (b) transformations of excluded minerals and (c) interactions of included minerals with excluded minerals, respectively. Vaporization and subsequent condensation of organically bound inorganic elements are not considered due to their low amounts in the high-rank coals.

The Poisson distribution of Eq. (1) is introduced to describe the random coalescence of particles in the included group, as well as the random fragmentation of excluded particles in the excluded group in this model, as shown in Fig. 1 [12,14,19–23]

$$P(k;\lambda) = \frac{e^{-\lambda}\times\lambda^k}{k!} \quad (k = 0, 1, 2, 3, \ldots), \tag{1}$$

where λ refers to the expected average coalescence number of the particles in the included group, or the expected average fragmenta-

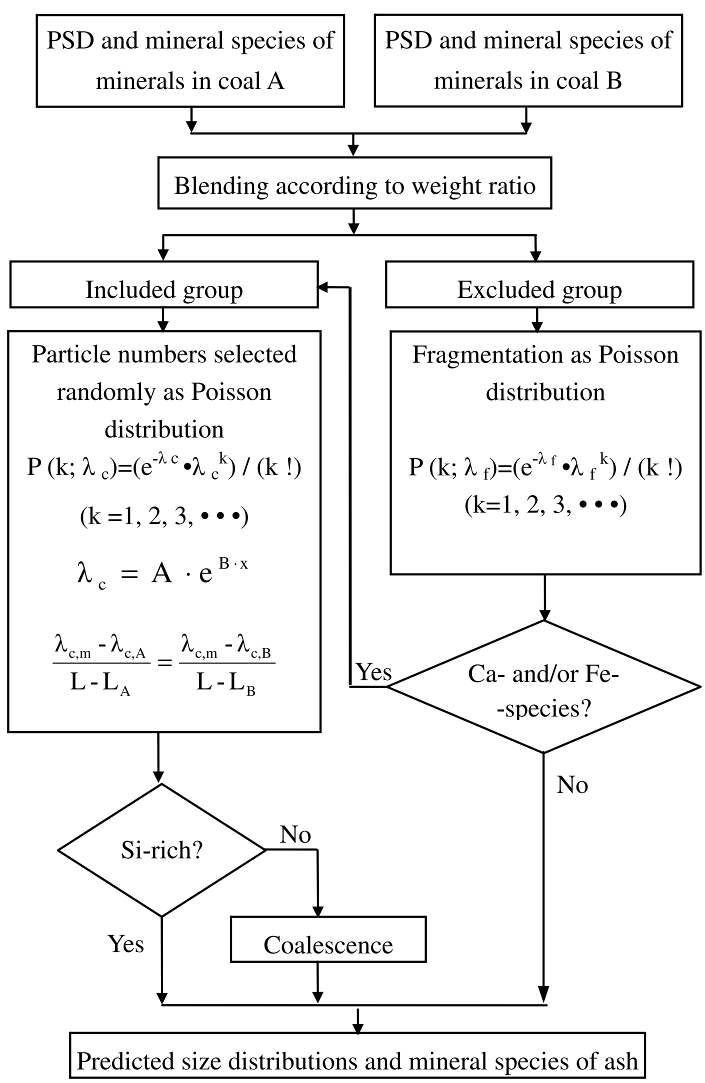

Fig. 1. Simulation schematic diagram of the current model.