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Temperature Effect on Central-Mode Particulate Matter Formation in Combustion of Coals with Different Mineral Compositions

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ABSTRACT: Coal combustion and mineral particle heating experiments were carried out in a drop-tube furnace at 1373 and 1573 K, respectively, to investigate the temperature effect on central-mode particulate matter (PM) formation during the combustion of coals with different mineral compositions. Two bituminous coals, coal A and coal B, with similar organic properties but different Ca/Fe mineral contents were tested. Typical minerals in the two coals, calcite and kaolinite, were used in the mineral particle heating experiments. An air atmosphere, a sample-feeding rate of 0.3 g/min, and a particle residence time of about 2 s were adopted in these experiments. The PM and bulk ash samples were collected by a low-pressure impactor and fiber filters, respectively, through a water-cooled N_2-quenched probe. The elemental compositions, mass concentrations of PMs, mineral compositions, and morphologies of bulk ashes were characterized. The results show that the mass fraction size distribution of aluminum (Al) can be used to identify the different PM formation modes. When the temperature is increased from 1373 to 1573 K, the central-mode PM concentration for coal A increases by 61.8%, whereas that for coal B decreases by 13.2%. The remarkable difference is attributed to different fragmentation and coalescence behaviors resulting from different mineral compositions of the two coals. The criteria of optimal coal mineral composition for melting-phase generation and coalescence occurrence are developed. Interactions between calcite and kaolinite and their influence on central-mode particle formation with respect to the temperature are clarified by the mineral particle heating experiments.

1. INTRODUCTION

Particulate matter with an aerodynamic diameter equal to or smaller than 2.5 μm ($PM_{2.5}$) is a major air pollutant in most Chinese cities, and coal-fired power plants are an important $PM_{2.5}$ source.[1] Figure 1 shows the formation mechanisms of coal-derived particulate matter (PM).[2,3] Dependent upon its formation mechanisms, PM can be divided into three formation modes: ultrafine mode, coarse mode, and a newly reported central mode [or fine-fragmentation mode (FFM)].[4,5] The ultrafine-mode particles are mainly formed by the vaporization−condensation mechanism;[2,6] the coarse-mode particles are mainly formed by char fragmentation and mineral coalescence;[7,8] and the central-mode particles are likely formed by fragmentation mechanisms, including char fragmentation,[3,7,9] mineral fragmentation,[3,10−12] etc. and direct transformation of the fine particles originally contained in raw coal.[3,13,14] The ultrafine-mode PM and part of the central-mode PM constitute the coal-derived $PM_{2.5}$. However, in comparison to the well-known ultrafine mode, the formation of PM in central mode is far less understood and warrants further investigation.

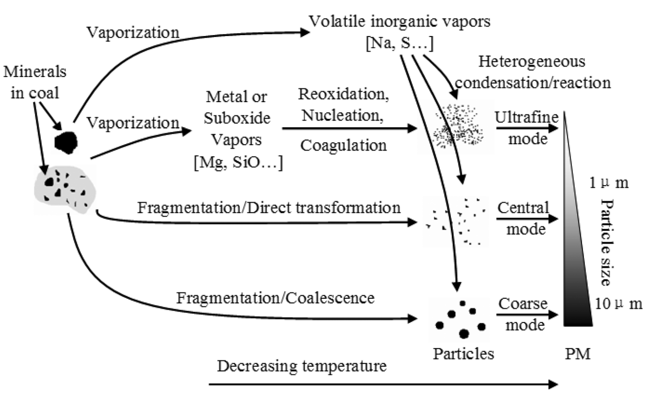

Figure 1. PM formation mechanisms during coal combustion.

The reaction temperature has a significant influence on PM formation during coal combustion. Numerous investigations have shown that the PM concentration tends to increase with an increase in the temperature.[15,16] However, available research on the effect of the temperature on central-mode PM formation led to different conclusions. By burning a size-classified Chinese bituminous coal, Yu et al.[3] observed that the central-mode PM concentration increased significantly when the temperature was increased from 1373 to 1673 K. However, during the combustion of an American bituminous coal, Fix et al.[17] found that the central-mode PM formation decreased slightly when the peak temperature was increased from 1508 to 1606 K. Buhre et al.[18] investigated five Australian coals and found that the $PM_{2.5}$ (central-mode PM was an important part) concentration displayed different variation tendencies with an increase in the temperature; it showed an obvious increase for four coals, whereas it remained constant for another coal (considering the increase in the ultrafine-mode PM concentration, the central-mode PM concentration for this coal decreased to some extent). The causes for the different results were not explored in the aforementioned literature. Never-

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