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The influence of vermiculite on the ash deposition formation process of Zhundong coal

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ABSTRACT

Zhundong coal, rich in the Alkali and Alkaline Earth Metal elements, causes severe ash deposition during the combustion in many power plants. In this paper, the influence of vermiculite, as an additive, on ash deposition formation and the corrosion phenomenon caused by ash deposition are investigated in a drop tube furnace system. The formation process of ash deposition under real working condition can be simulated in this furnace system. The results show that vermiculite has a significant inhibition effect on the formation and growing process of ash deposition, as well as the corrosion phenomenon. At the beginning of ash deposition, the swelling vermiculite can effectively absorb the SO_2 in the flue gas, which restrains the formation of Na_2SO_4 in the inner ash, close to the surface of heat exchangers. The mineral in internal inner ash gets changed and the phenomenon of corrosion on the heat exchangers surface gets alleviated. Meanwhile, the external inner ash presents with loose structure instead of the molten condition, which lowers possibility for ash deposition to grow. In outer ash deposition, close to the flue gas, the content of layered particles with high melting point, as Mg_2SiO_4, increases and viscous particles, like $Ca_2Al_2SiO_7$, are separated from each other by the force of the vermiculite swelling. As a result, adding vermiculite makes it hard for ash deposition to form and grow. According to the experiments, with more than 5% blending ratio of vermiculite, the vermiculite additive has a positive effect on restricting the ash deposition.

1. Introduction

Zhundong coal field, the biggest in the world, has the estimated reserve of about 390 billion tons [1], and the proved reserve is 213.6 billion tons [2]. With respect to energy consumption structure of China, coal will still occupy a comparatively large proportion in the energy sector for a long period. Accordingly, Zhundong coal can meet the demand of China energy consumption in a large extent. Considering Zhundong coal has the character of low ash yields, low S content, middle-to-high calorific value and high burn out rate, it's regarded as a good steam coal [3]. However, for most Zhundong coal, the amount of Alkali and Alkaline Earth Metal elements is usually higher than other steam coal; for instance, the Na_2O and CaO in coal ash are more than 5% and 30%, respectively [4]. As a result, it will cause serious ash deposition, corrosion on the surface of the heat exchangers. The mentioned adverse effects limit the utilization of Zhundong coal in power plants.

The phenomenon of ash deposition has a close relation with the slagging and fouling [4–9]. Slagging is usually defined as that partially or completely molten materials attach to the heat exchangers surface in the radiation heat transfer area. Fouling is usually defined as that the materials condense or sinter on the heat exchanger surface in convective heat transfer area [6]. Serious ash deposition mainly occurs near the convective heat exchanger during the combustion of Zhundong coal [4]. The ash deposit can be clearly divided into two parts: inner layer and outer layer. The inner layer, also called initial layer, is close to the cold side and mainly consists of fine particles less than 10 μm. Na, Ca, K, Cl and S are the primary elements in those ultrafine particles, which will deposit on the metal tube by the force of thermophoresis. Meeting the low-temperature surface of heat exchangers, those ultrafine particles will condense on them and that results in the formation of sticky layer. The outer layer mostly consists of larger particles caught by sticky layer and these particles are usually bigger than 10 μm. Ca mineral in coal ash can react with alkali and alkaline earth metal oxides to give low temperature eutectic [5,9]. Overall, previous studies indicate that the high alkali and alkaline earth metal content in coal is the main cause for ash deposition during the utilization of Zhundong coal in the boiler [10]. Meanwhile, the ash deposition usually incurs the corrosion phenomenon, the oxidation reaction between the surface of heat exchangers and the ash deposit. The surface of heat exchangers gets

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Table 1
The proximate and ultimate analysis for untreated coal (wt%, ad).

Proximate analysis			
M	A	V	FC
18.81	6.32	33.43	41.44

Ultimate analysis				
C	H	O	N	S
57.99	2.88	13.13	0.83	0.05

M, Moisture; A, Ash; V, Volatile; FC, Fixed Carbon; ad, air dry basis.

wrinkled when the corrosion happens and the wrinkled surface are easy to fall off. The flue gas goes through the ash deposit, forms the sulfate under high-temperature environment, and corrodes the surface metal [13]. The corrosion is caused by the complex reaction among the sulfate, the oxidizing gas and the surface metal [14]. Meanwhile, the surface metal gets corroded by reacting with the oxidizing gas, which diffuse to the surface metal through the ash deposit [15,16]. And they claim that the key to the corrosion is the formation of sulfate on the heat exchange surface [17].

Blending additives has been one of the most effective ways to alleviate ash deposition. Many scholars have investigated the influence of additives which are rich in silicon and aluminum content, such as kaolin, bauxite and silica [18–24]. Vuthaluru et al. [18] believe that sodium can be effectively captured by clay-type mineral additives, and that can effectively reduce fouling. Wei et al. [19] find that SiO_2, kaolin and fly ash can effectively restrain the evaporation of sodium during Zhundong coal combustion. Vassilev et al. [20] test the dependence of ash fusion characteristics on ash composition. They find that the Si, Al and Ti can increase the ash fusion temperatures and recommend additives based on Si and Al. Shen et al. [21] point out that the varying proportions of Ca_2SiO_3, $Ca_2Al_2SiO_7$ and $CaAl_2Si_2O_8$ can influence the ash fusion characteristics by studying the effect of kaolin on combustion. Ash deposition can be controlled by varying the proportions of ash content. To solve the corrosion caused by ash deposition, the current researches mainly focus on the heat exchangers material, coating and the combustion model [22,23]. Only a few scholars select $CaCO_3$ and $MgCO_3{\cdot}CaCO_3$ as additives to control the corrosion [24].

Vermiculite has previously been found to relieve ash deposition significantly as ash deposits are loose and easily removed after the introduction of vermiculite [25]. Vermiculite is rich in Si, Al and with swelling capacity after heat treatment, and that makes it possible to be an effective additive. The action mechanism of vermiculite in relieving ash deposition is different from the regular additive. The similarity is that the viscosity of ash deposit gets lowered because the minerals with high ash fusion point will be produced by the reaction between the blending additives and fly ash. The different is that swelling and curling of vermiculite after heat treatment restrain the agglomeration of ash particles [25]. Thus, vermiculite has been proven to be a potential additive against the ash deposition. However, it is still unknown that the role the vermiculite plays in the each part of ash deposition during its formation process. Our group design the experiments in a drop tube furnace to study the influence and the mechanism of vermiculite on ash deposition formation process during the Zhundong coal combustion. Meanwhile, the optimal blending ratio of vermiculite are given, which provides the guidance for vermiculite industrial utility in the combustion of Zhundong coal.

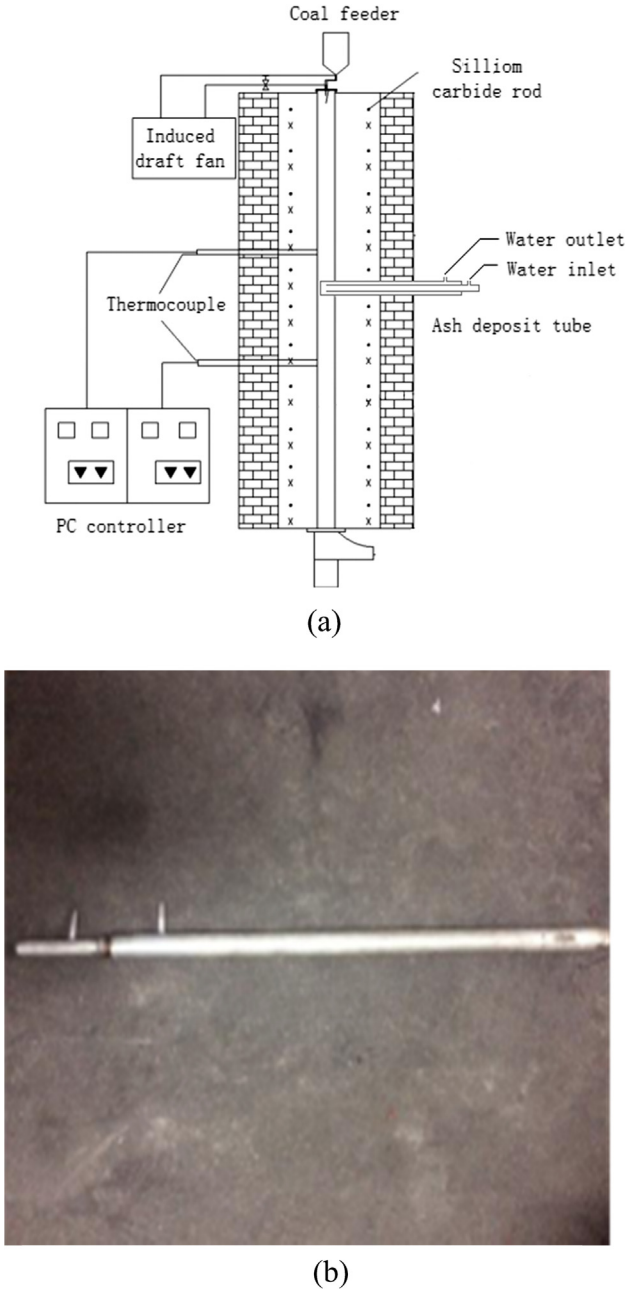

Fig. 1. Diagram of experiment system: (a) Schematic diagram of the drop tube furnace system; (b) Photo of water-cooled ash deposition tube.

2. Experiment materials and scheme

2.1. Coal and vermiculite analysis

Shaerhu coal, a representative type of Zhundong coal, is selected for investigation. The Shaerhu coal is regarded as good steam coal for characteristics of high volatile yield, low ash content and low moisture content. The content of Na and Ca are 5.94% and 38.6% respectively,

Table 2
The chemical composition of coal ash and vermiculite (wt%, ad).

	Na_2O	K_2O	CaO	MgO	Fe_2O_3	SiO_2	Al_2O_3	SO_2	H_2O
Untreated coal	5.94	0.12	38.60	3.87	5.86	23.72	15.15	5.04	–
Vermiculite	1.35	2.56	1.82	17.60	6.57	40.28	16.24	–	6.28