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Research Paper

Investigation of characteristics and formation mechanisms of deposits on different positions in full-scale boiler burning high alkali coal

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HIGHLIGHTS

- The deposits sampled at different positions in the full scale boiler burning high alkali Zhundong coal.
- The layered slagging behavior at platen superheater during high alkali coal combustion was studied in full-scale.
- The inorganic constitutes in fume (temperature is about 1000 °C) were classified into gas, solid and molten.
- The chemical reaction mechanism of layered slagging at plate super-heater during long time operation was proposed in detail.

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ABSTRACT

Zhundong coalfield are huge in China; however, high alkali contents induce severe slagging and fouling problems in boiler. To obtain the characteristics and formation of deposits in boiler burning high alkali coal, the deposits at different positions were sampled in a 350 MW boiler burning Zhundong coal, and analyzed by X-ray Fluorescence. The results indicated that the slagging was deteriorating from bottom to top at water wall. The slag with obvious layer structure only presented at platen superheater. The deposits in horizontal flue were mainly formed from the solidified particles attachment. To further understand the formation mechanism of layer structure in slag at platen superheater, the slag was separated according to the morphology and each layer was analyzed by X-ray Diffraction. The results suggested that through the condensed $CaSO_4$ was the main compounds for the strong thermophoresis in layer 1, the little fused particles with high sodium content played the key bonding role. For layer 2, the fused particles contain high sodium content adhered to deposit surface and formed melt surface, which capture the other particles. The Fe species captured by melt surface lower the melting temperature of the formed deposit, and then aggravated the deposit fusibility in layer 3.

1. Introduction

Coal is the most important source of energy around the world, and this energy source would most likely last a long time. Coal consumption is high especially in China, exceeding 50% of the total amount of coal used globally. More than 70% of the generated energy is still produced by thermal power plants [1]. The Zhundong coalfield, which is located in Changji, Xinjiang province, is the largest integrated coalfield in China. To date, the coal reserves in this region hava been estimated to amount 164 Gt, with this region having priority to develop in future [2,3]. At present, the price of Zhundong (ZD) coal is very low (80 CNY/t) for the coal is opencast and easily exploited. ZD coal has a lot of advantages such as high volatility and low ash and sulfur content. Therefore, an increasing number of power plants tend to burn ZD coal to reduce the production costs [4]. However, the sodium content of ZD coal is very high, resulting in serious problems such as slagging and fouling on the heating surface of the boiler, especially on the platen superheater area [5].

During boiler operation, the gas temperature at the platen superheater area is about 1273 K. The gaseous inorganic minerals and partly fused ash particles coexist in the flue gas. In general, ash species are deposited on the boiler tubes from the flue gas mainly through three transport mechanisms: diffusion, thermophoresis and inertial impaction [6]. Tomecezk [7] pointed out that thermophoresis is the primary transport mechanism for submicron particles (<1 μm) to adhere to boiler tube. Fine particles (1–10 μm) are principally controlled by turbulent diffusion to stick

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to the tube surface; for large particles (>10 μm), inertial impaction is the most important transport mechanism.

Wang [8] reported that Na_2O, CaO, and SO_3 contents in Zhundong coal ash is generally higher, reaching 4%, 20%, and 20%, respectively. Many researchers have suggested that sodium plays a vital role in the slagging problem during the Zhundong coal combustion [9–12]. In Zhundong coal, more than 70% of sodium is water soluble, which is released into gas to form gaseous sodium salts in the initial combustion stage [13,14]. The rest of the sodium are sodium aluminosilicates with lower melting temperature [15]. The condensation of gaseous sodium salts, impact and adhesion of fused sodium aluminosilicates lead to serious slagging during boiler operation. However, the formed slag still under the higher temperature. The chemical reaction occurred in the formed slag was not clear.

Slagging caused by calcium and iron in Zhundong coal has attracted considerable attention in recent years. Dai et al. [16] studied ash samples from various heating surfaces in a 300 MW subcritical boiler burning high-alkali coal and found that when gas temperature is reduced to the range of 1073–1273 K, mass fractions of Ca, Mg, and S in ash samples were relatively high. A previous work [8] observed that Ca and S contents in the ash collected at furnace outlet and horizontal flue (gas temperature is about 1273 K) were higher than others areas in a 300 MW boiler burning high-alkali coal. The iron species contributed to slagging during coal combustion [17]. Ash particles with Fe_2O_3 mass fraction exceeding 5% easily fused and adhered to the heating surface. Iron species have been generally used as flux agent to reduce melting temperature for the lower melting temperature and fluxing of Fe^{2+} formed under reducing atmosphere condition [18,19]. Recently, Dai et al. [20] found that the addition of external silica changed the constitution of iron and promoted the precipitation of Fe^{3+} on the surface silica matrix. In ZD coal, the content of CaO and Fe_2O_3 in coal ash is usually more than 20% and 10%, respectively indicating that Ca and Fe also play an important role in ZD coal slagging. However, how Ca and Fe participate in slagging during high-alkali coal combustion has not been clearly specified.

Naruse [21] reported the existence of a layered structure in the deposits on high-temperature tubes. The initial layer of about 30 μm thickness is comprised of fine particles <3 μm while the main deposit body is comprised of molten slags. In addition, the observed variation of SiO_2–Al_2O_3–others in different layers does not clarify effect of the alkali content; therefore, the effect of whether ash fusibility has a significant effect on slagging and whether it is applicable to the slagging behavior of high-alkali coal needs to be addressed. The high potassium content in biomass also induces serious slagging problems [22]. A previous work also found the layered structure in the slags of full-scale boiler burning biomass as shown in Fig. 1 [23]. The thickness of each layer in the full-scale boiler was much larger than the results of Narese. Although sodium and potassium belong to one family, their chemical properties are significantly different; whether slags occur in the layered structure during high-alkali coal combustion remains to be studied.

Zhou [24] and Wu [25] conducted ash deposition experiments of high-alkali Zhundong coal in lab-scale furnace and found obvious layer structures in the deposits, which suggested that the initial layer was composed of sulfates and that the outside layers were produced by fused or impacted solid ash particles that adhered to the molten deposit surface. However, disagreements as to the element distribution in the different layers have arisen, particularly as to whether Fe is enriched in the initial layer, and the occurrence of Ca, which is composed mainly of sulfates or aluminum silicates. These disagreements should be verified using a full-scale furnace, because the time for ash deposition in the lab-scale furnace is relatively short and the operation condition is relatively stable. Conversely, the time for ash deposition in the full-scale furnace is long, and the deposit surface temperature in the furnace is frequently changed with boiler load variation. The fused or solid particles in the deposits react with each other after the slags are formed. The chemical reaction mechanism during the long-time process of slags formation remains ambiguous.

Based on the above analysis, it can be seen that the high alkali content in coal induced serious slagging and fouling problems were attracted widespread attention. However, the research of long-time deposition during high alkali coal combustion in the full-scale furnace was rarely reported. The properties of deposits at different area in the furnace also remains ambiguous. Furthermore, whether the layered slagging occur during the full-scale furnace burning high alkali coal should be verified. In this study, to obtain the slagging status and the formation mechanism of deposits at different positions, the slags were sampled at the water wall, platen superheater and tubes in the horizontal flue in a 350 MW boiler which burned high alkali Zhundong coal. The ash samples were analyzed by X-ray fluorescence (XRF) and X-ray diffraction (XRD) to determine the element distribution and the mineral composition. According to the analysis results and the morphology, the formation of slags at different position in the full-scale boiler was analyzed in detail. Especially for the slag with layer structure at platen superheater, a layered slagging mechanism during high-alkali coal combustion was proposed.

2. Experimental sections

No boiler is completely operated on ZD coal because of its strong slag and fouling property. At present, the kaolin additive was blended into ZD coal to mitigate the severe slagging problems. Therefore, a 350 MW boiler that burns ZD coal with kaolin additives was investigated to obtain the slagging characteristics of ZD coal in the furnace.

2.1. Coal and additive samples

The primary coal used in this study was high sodium and calcium lignite from the Zhundong district of Xinjiang province. The kaolin additives were from the surrounding area; its composition is shown in Table 1. The total amount of SiO_2 and Al_2O_3 in kaolin additives accounts for more than 90%.

This experiment continued for nine months and 149 types of original coal have been used. The coal, after kaolin blending before combustion, was analyzed five times per day; about 737 kinds of blending coal were analyzed for ash composition, fusion temperature, and others. The average contents of Na, Ca, Al, and Si in the 149 kinds of original coal are 3.0%, 22.1%, 7.9%, and 13.5%, respectively. The comparison of Na-Si content before and after kaolin blending is shown in Fig. 2. After kaolin blending, the average content of Na and Ca decreased to 2.1% and 13.8%, respectively, whereas that of Al and Si increased to 13.5% and 45.5%.

2.2. Sample collection and analysis method

In this study, a 350 MW corner tangential boiler burning Zhundong coal was studied; the boiler structure is shown in Fig. 3. When the boiler shutdown, the deposits were sampled in the boiler. The sampling points were set at 6 different positions in the boiler: (1) Five meters below the burner at water wall(A-WW I); (2) The bottom of combustion zone at water wall (B-WW II); (3) Four meters higher than the separated overfired air(SOFA) (C-WW III);