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Ash limitation of physical coal beneficiation for medium–high ash coal—A geochemistry perspective

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HIGHLIGHTS

- We studied the possibility of reducing the coal ash content geochemically.
- A significantly correlation between ash yield and $Al_2O_3 + SiO_2$ content is obtained.
- The intercept of regression equation on the ash axis is generally 2–5%.
- The intercept of 2–5% indicates an original inorganic component in coal-forming peat.
- 2–5% of inorganic components in the coal can hardly be separated by physical cleaning.

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ABSTRACT

Nowadays the industrial coal beneficiation in China could only reduce the ash yield to about 10%, which could not meet the requirement or standard of environment protection. In this work, the possibility of reducing the ash yield was studied from the aspect of geochemistry. The channel samples were collected from two coal seams in Guizhou and Shanxi province, China and then conducted analysis by combining data from coals worldwide. The result reveals that the same coal seam or the coals deposited in the same peat swamp show a significantly positive correlation between ash yield and $Al_2O_3 + SiO_2$ content, and the intercept of regression equation on the ash axis is always less than 5% (generally 2–5%). Overall, the coal from China is featured with a higher intercept compared with that in the other countries. The intercept of 2–5% on the ash axis indicates an original inorganic component in coal-forming peat. The research result also presents a theoretical limitation of coal ash by coal cleaning, because 2–5% of inorganic components in medium–high quality ash coal could hardly be separated by traditional physical coal beneficiation.

1. Introduction

Coal plays an important part in the industrial production and daily life in China, with about 74% of total primary energy and 60% of chemical materials derived from coal production [1]. At present, China has become the largest consumer and producer of coal in the world. Between 2011 and 2013, the total coal production in China was 3.52, 3.66 and 3.7 billion and its corresponding consumption was as high as 3.8, 3.91 and 3.61 billion, accounting for more than half of consumption in the world.

The energy structure featured as coal domination would not change in the near future [2], which, on the other hand, results in serious air pollution in China. To a great extent, the widely spread of fog and haze and the serious air pollution of $PM_{2.5}$ in most Chinese cities recently is attributed to the combustion of coal [3–6]. According to recent studies, a number of human health problems are related to the volatilization of trace elements during coal combustion and coal gangue stacking [1,7–13].

Although traditional physical coal washing method could reduce the ash yield in coal to a great content, the coal beneficiation plant in China could only reduce the ash yield to about 10% at present [14,15]. On the other hand, the big environmental problem and limited transportation budget due to the utilization of this coal force us to seek a way to further reduce the ash yield in coal during production. According to Tomeczek and Palugniok [16],

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the inherent minerals in coal are closely associated with organic matters and could not easily be separated, and the percentage of those inherent minerals in coal is usually below 10%, mostly 2–4%. Unfortunately, the current technology used in coal processing could not produce coal with about 2–4% ash yield [17–19].

Coal is a complex heterogeneous mixture of organic and inorganic components with different abundance and origin [20–22]. The ash yield in the coal is the residue derived from the inorganic and organic matter during the incineration of the coal. The ashes from coals differ in type and origin, and those from identical coals differ in the ash yield, which often shows a diverse distribution of the essential components [23]. In order to study the genesis of the inorganic matter during coalification, the correlations between ash yield and ash-forming elements have been studied based on the samples from coal deposits in German, Russian, Ukrainian, Spanish, Canadian and Romanian [24]. It is commonly accepted that the elements which are positively correlated with ash value are ‘imported’, whereas the elements which are negatively correlated with ash value are authigenic [25]. Generally, Si and A1 are the major components of the ash, and the proportion of detrital minerals increases along with the increase of the ash yield [24]. In other words, the composition of ash is close to the composition of the adjacent rocks with the increase of ash yield in the coal [23].

In order to study the possibility of reducing the ash yield in coal from the aspect of geochemistry and the theoretical limitation of coal ash during physical coal beneficiation, samples were collected from two coal seams in China and conduct analysis on the compositions of ash yield and $Al_2O_3 + SiO_2$ (or Al + Si). The data from other countries published previously are also included for analysis and comparison.

2. Geological background

Five coal-distribution areas in China have been classified according to their geotectonic units and coal forming period [1]. Among them, northern China (especially Shanxi province) and southwestern China (especially eastern Yunan and western Guizhou province) are the main coal production bases in China and have distinct characters in terms of sedimentary environment and original coal-forming plants.

The Puan coal mine is located in the Puan County of western Guizhou province, Southern China (Fig. 1). The No. 17 coal seam where the samples were taken belongs to the Longtan Formation of the Late Permian age, with a thickness between 0.8 m and 6.2 m, average at 3.1 m. The geological background has been described in detail by Dai et al. [26].

The Antaibao coal mine is located in the west part of the Pingshuo city, Shanxi province, northern China (Fig. 1). Its geological background is provided in our previous studies [27–29].

3. Sampling and analytical method

Eight incremental channel samples (approximately 15 cm across and 10 cm deep) were collected from the Puan coal mine, according to the macrolithotype of coal seam, of which ply two contains a thin layer of carbonaceous mudstone parting. In addition, a whole seam mixed sample was also collected. All samples were stored in plastic bags during transportation in order to avoid the contamination and oxidation.

The samples were crushed and ground to less than 200 mesh for further test. Proximate analysis (ISO-1171 [30]) and chemical analysis were performed on the samples, and an X-ray fluorescence in (XRF, Cu Ka source) analysis was performed in Advanced Analysis and Computation Center of China University of Mining and Technology, correspondingly (Table 1).

The specific sampling and analytical method of Antaibao samples could be seen in our previous studies [27,29].

4. Results and discussion

The result of the ash yield and analysis of nine samples from Puan coal mine are shown in Table 1. Fig. 2a shows the relationship between ash yield and $Al_2O_3 + SiO_2$ which were obtained by separating the anomaly samples. The anomaly samples are mainly high ash yield coal gangue. It can be seen from Fig. 2a that there is a positive correlation between ash yield and $Al_2O_3 + SiO_2$ content in the coal. The analysis result of twenty-two channel samples from Antaibao mine is presented in Fig. 2b (the result of Plies 21 and 22 samples are not included due to their anomaly [29]).

Attention has been paid to the occurrence and origin of minerals in coals by many researchers [31,32]. According to Stach et al. [33], the inorganic components of coal are divided in three groups: (1) inorganic matter from the original plant; (2) inorganic–organic complexes and minerals which formed during the first stage of the coalification process or were introduced by water or wind into the coal deposits as they were forming; (3) minerals deposited during the second phase of the coalification process, after the consolidation of coal, by ascending or descending solutions in cracks, fissures or cavities or by alteration of primarily deposited minerals. As seen in Fig. 2, the intercept of $Al_2O_3 + SiO_2$–Ash regression equations on the ash axis is 3–5%. This value has the geological significance since it represents the original inorganic component of the coal-forming peat swamp, including the minerals of the above first two groups. It is possible that the content of the original inorganic components of the peat swamp is less than 5%, taking into account the inherent ash of plant generally less than 0.5% and the inorganic matter present in the peat swamp medium. The primary minerals are generally not more than 2% of the coal [34].

In any case coal cleaning depends on mode of occurrence of the minerals. The above first two groups, sometimes described as inherent mineral matter are closely associated with the organic matter of coal, including both intimately admixed minerals and nonmineral inorganics in the maceral components. The minerals of the third group derived from intra-seam noncoal bands or admixed roof or floor strata during coal mining are described as extraneous mineral matter. Inherent mineral matter could hardly be separated by the traditional physical beneficiation method, whereas extraneous mineral matter can be at least partly removed by the cleaning processes at coal preparation plants.

Stach et al. [33] thought that the minerals which have formed together with the coal or have been introduced into the deposits are, as a rule, fine-grained and intimately intergrown with the coal; by contrast, the minerals which formed during the second stage of the coalication process are neither fine-grained nor intimately intergrown with the coal, because most of them were deposited in cracks and fissures. In general, the secondary transformation, with or without the introduction of new material, of minerals which formed during the first phase of the coalication process does not alter the intimate intergrowth between these minerals and the coal, and rarely leads to an increase in grain size.

As shown in Fig. 2, even if the ash-forming elements Al and Si have been largely removed, there are still 3–5% of the coal ash-the intercept on the ash axis, indicating that the intercept of 3–5% could be the theoretical limitation of the coal ash with physical coal cleaning. As for these minerals deposited during the second phase of the coalification process by ascending or descending solutions in cracks, fissures or cavities directly lead to the increase of ash yield, but they can be separated by the traditional physical beneficiation method.