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Review

Thermal effects on arsenic emissions during coal combustion process

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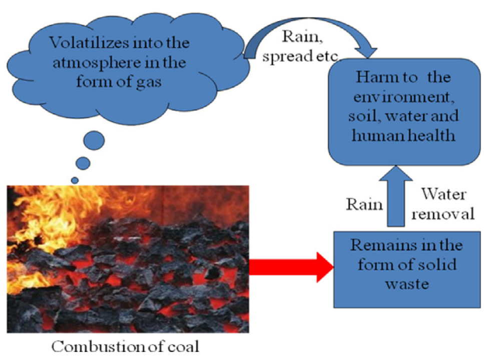
HIGHLIGHTS

- We studied the variation of arsenic emission during the combustion process of coal.
- The relationship between emission rate of arsenic and several important factors is researched.
- The measure to reduce arsenic pollution in the process of coal burning is given.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, the rate of emission of arsenic during the burning process of different kinds of coal is examined in order to study the volatile characteristics of arsenic during coal combustion which have negative effects on the ecological environment and human health. The results show that the emission rate of arsenic gradually increases with increased burning temperature, with a threshold of approximately 700 °C to 800 °C in the process of temperature increase. Then, the relationships among the arsenic emission rate and combustion environment, original arsenic content, combustion time, burning temperature, air flow and amount of arsenic fixing agent are discussed, and it is found that except for the original arsenic content, the rest of the factors have a nonlinear relationship with the emission rate of arsenic. That is, up to a certain level, they all contribute to the release of arsenic, and then their impact is minimal. The original arsenic content in coal is proportional to the arsenic emission rate. Therefore, taking into consideration the nonlinear relationships between factors that affect the arsenic emission rate can reduce contamination from arsenic.

Contents

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1. Introduction

Coal is the main energy source in China, and not only is a large amount of heat produced during coal combustion, but trace elements are also discharged, which can incur serious damage to the environment and human health (Guo et al., 2004; Kang et al., 2011; Li et al., 2012).

Among the emitted trace elements, arsenic (As) has received much attention due to its toxicity and carcinogenicity. Studies have shown that As released from coal can pollute the atmosphere, water and soil in a gaseous or chemical form, thereby affecting human health (Wang et al., 2006). For example, statistics (Liu and Chen, 2015) show that in Guizhou Province in China, more than one hundred thousand people are suffering from potential As poisoning, in which there are over 2000 patients who have been poisoned due to drinking water that contains high levels of As, eating food that are prepared by using coal that is highly arsenic, and breathing (the amount of As in the air exceeds standards). Moreover, hundreds of people suffer or have died from the repercussions of As pollution, such as skin, liver and lung cancers. At present, there is no optimal method to counter As poisoning, so there are some restrictions in place for coal mining in which large amounts of As are emitted, but these can result in the waste of resources. Therefore, a study on the standards imposed onto arsenic emissions and the precipitation mechanism of coal combustion would have great theoretical impacts and practical significance for the prevention and control of As pollution as well as improvements in the utilization of resources.

To date, many researchers have studied the precipitation of As in the coal combustion process (Bolanz et al., 2012; Frandsen et al., 1994; Liu and Su, 2014). For example, Yu et al. (2009) found that there is a positive correlation between As content in indoor and outdoor air and that of burning coals. Sun et al. (2004) examined the distribution of As in fly ash with different particle size in coal-fired power plants, and found that the concentration of As in different concentrations of particulate matter is gradually increased with a reduction in the particle size of fly ash. Some academics have conducted statistical analysis on the distribution of As in coal in China, and obtained a distribution range of 0–10 μg/g (with an average value of 5 μg/g), which is similar to the average content of As in coal worldwide (Wang et al., 2013; Yudovich and Ketris, 2005; Zhang et al., 1999). Liu et al. (2016a) studied the volatilization of As during the co-combustion of lignite blends with high As levels. Contreras et al. (2009) examined the effects of different compounds in the distribution and mode of occurrence of As in co-combustion processes based on thermodynamic equilibrium calculations. The mineral association, chemistry, distribution and migration of As in different kinds of coal have also been assessed by using different methods, such as using a low temperature ashing process and density fraction) (Jiao et al., 2013; Low and Zhang, 2013; Zhou et al., 2016). These studies all provide a better understanding of the migration and distribution of As in the coal combustion process and a solid foundation for future work. Since As emissions have continued to pollute air, thus negatively affecting the environment and human health, and studies on the origins and process of As emission are relatively rare, As emission is still an area that needs to be improved and studied in-depth.

In this paper, the variations in the emission rate of As during the burning of different types of coals under different combustion environments are examined, and the relationships among the As content, air flow, combustion time, oxygen content and As emission are analyzed. Then, the process of As emission is tested by using a thermogravimetric test. The results can further understanding on the source of As volatilization during the coal combustion process and provide guidance and direction on the prevention and control of As pollution (Tang et al., 2009; Zhao et al., 2017).

2. Data sources

Arsenic produced through coal combustion is becoming a more popular research topic because of its toxicity and volatility as well as its potential carcinogenic propensity (Liu et al., 2016b). In China, there is uneven distribution of As in coal in the different areas. In general, the concentration of As in Chinese coal is similar to that of the global average value, which is around 5.0 ppm. However, depending on the geochemical and geological characteristics of the particular coal, As concentrations can vary and change significantly in different regions (Zhao et al., 2008). Coal found in northern and northwest China has much lower concentrations of As than that in the southwest and northeast of China (Zhao et al., 2008), especially in the southwest of Guizhou (Chen, 2013; Liu and Chen, 2015; Yu et al., 2009). For instance, the coal in northern and northwest China such as Northern Shaanxi province typically have a concentration of 4.1 ppm while that in southwest and northeast China such as Guizhou have 7.5 ppm. There have been many coal-forming periods in the Guizhou area, and all sorts of coal is found. Aside from stone coal with a large amount of ash formed in the early Paleozoic, there is also lignite formed in the Tertiary period, which has the greatest amount of bitumite and anthracite which formed in the upper Permian and upper Triassic periods. The coal formed in this period is widely distributed, and the geological circumstances of coal formation are diverse with complex structures, which result in higher amounts of trace elements, especially As. Studies (Liu and Chen, 2015; Zhao et al., 2008) have shown that high concentrations of As in coal are mainly derived from the migration of magmatic fluid after the coal forming period, and the distribution is mainly related to the geological structure, especially the composite zones in tectonic settings, and large and deep faults. In this paper, we have collected data published in the literature (see Table 1) on the As emission from coal in Guizhou, Shanxi, Henan, Yunnan, Hunan and Jiangxi (all Chinese provinces) and the coal has high concentrations of As. A comparative analysis is carried out, and we provide a better understanding of the emission information during the thermal process of coal combustion.

3. Experimental results

Previous studies have shown that the level of As emissions varies with the burning temperature in the coal combustion process (Senior et al., 2006; Sia and Abdullah, 2012; Su et al., 2013). Generally speaking, As in coal is mainly in the form of arsenic pentoxide (As_2O_5), which is a white solid, at a temperature below 477 °C. When the temperature increases from 477 °C to 627 °C, As changes in form to first As_2O_5 which is a solid phase, and then arsenious oxide (As_4O_6) and arsenic trioxide (AsO), which are gas phases; that is, from 477 °C to 527 °C, As is mainly in the form of As_2O_5 which is a solid; from 527 °C to 557 °C, As is mainly in the form of As_4O_6, which is a gas; and from 557 °C to 627 °C, As is mainly in the form of AsO, which is also a gas. When the temperature is higher than 627 °C, the As in coal is found only in the form of AsO or a gas phase. The rate of released As and total amount of As are therefore primarily related to the combustion environment, As concentration in the coal, combustion temperature, a constant time and the oxidant or inhibitor contents (Song et al., 2014; Zhao and Luo, 2017).

Fig. 1 shows the changes in the emission rate of As (the formula is shown in Eq. (1)) in the coal combustion process under natural