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Review

Research and industrialization progress of recovering alumina from fly ash: A concise review

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ABSTRACT

Fly ash, a by-product of high temperature combustion of coal in coal-fired power plants, is one of the most complex and largest amount of industrial solid wastes generated in China. Its improper disposal has become an environmental problem. Now it is widely realized that fly ash should be considered as a useful and potential mineral resource. Fly ash is rich in alumina, making it a potential substitute for bauxite. With the diminishing reserves of bauxite resources, as well as the increasing demand for alumina, recovery of alumina from fly ash has attracted extensive attention world-wide. The present review describes, firstly, the generation and physicochemical properties of high alumina fly ash found in northern China and then focuses on the various alumina recovery technologies, the advantages and disadvantages of these processes, and in particular, the latest industrial developments. Finally, the directions for future research are also considered.

Contents

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1. Introduction

Fly ash is a by-product of high temperature combustion of coal in coal-fired power plants (Shemi et al., 2012). China is now the largest coal producer and consumer in the world (Salameh, 2003; Zha, 2006). With the increasing consumption of coal, the emissions of fly ash from coal-fired power plants have become the largest industrial solid waste in China (Yao et al., 2015b). Fig. 1 shows the generation of coal fly ash in China from 2002 to 2015. Annual generation is continuously increasing and expected to reach 620 million tonnes by 2015 (Li et al., 2015). Although China's energy structure is changing with the increase of renewable energy proportion, the consumption of coal remains the largest and will not decline dramatically in the next few decades (Li et al., 2012). So the emissions of fly ash will remain a serious environmental problem.

The environmental impact of fly ash is now being fully recognized. The utilization rate of fly ash in China has increased greatly, reaching a higher level of 68% in 2014 compared to 20% in 1999 and 14% in 1980. It is expected to reach 70% by 2015 (Yao et al., 2015a). However, fly ash produced in China has mainly been used in some applications with low economic benefits, e.g. as fillers in brick manufacturing and road or dam construction. Nevertheless, large amounts of fly ash are still dumped into ponds or piled on land causing a serious environmental problem, especially in Inner Mongolia or Shanxi Province in China. To utilize more fly ash and decrease its negative impact, it needs to turn fly ash to a high value-added product. Based on such ideas, some researchers have been trying to recycle coal fly ash as industrial mineral resources for, e.g., foam glass (Chen et al., 2011), zeolite (Zhou et al., 2014), glass ceramics (Rawlings et al., 2006), and mullite ceramics during last decades (Blissett and Rowson, 2012; Li et al., 2009).

Recently a new type of fly ash called high alumina fly ash (HAFA) has been discovered in North Western China. HAFA is seen as a potential raw material for recovery of alumina since its alumina content can reach 40–50 wt%, far higher than the normal fly ash and close to that of middle-grade bauxite. The annual production of HAFA is estimated to be 50 million tonnes, which contains approximately 20–25 million tonnes of alumina, making it a potentially attractive substitute to bauxite (Yuan et al., 2015). The majority of bauxite, the main aluminum source for various industrial applications, is dependent upon import at present in China. The domestic and import situation of bauxite in China is shown in Fig. 2. The import volume was higher than the domestic production in 2013, therefore, recovering alumina from HAFA potentially provides a significant opportunity for converting waste materials to a new aluminum source, and has been a research focus in China for the last decade (Zhong et al., 2009).

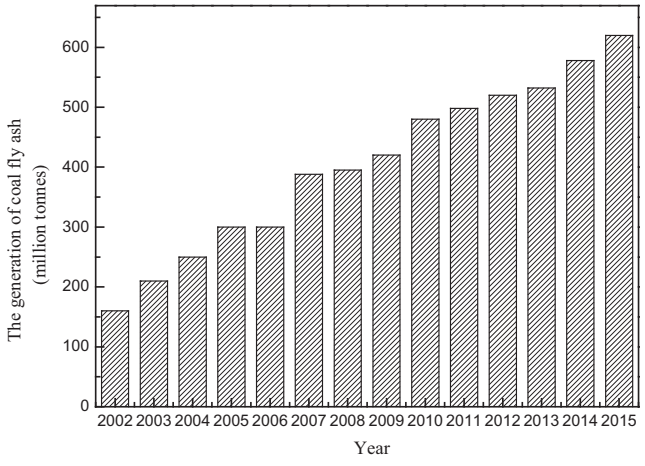

Fig. 1. The generation of coal fly ash in China in 2002–2015. Note: Data sourced from website of Sina Finance and China's Industrial Information.

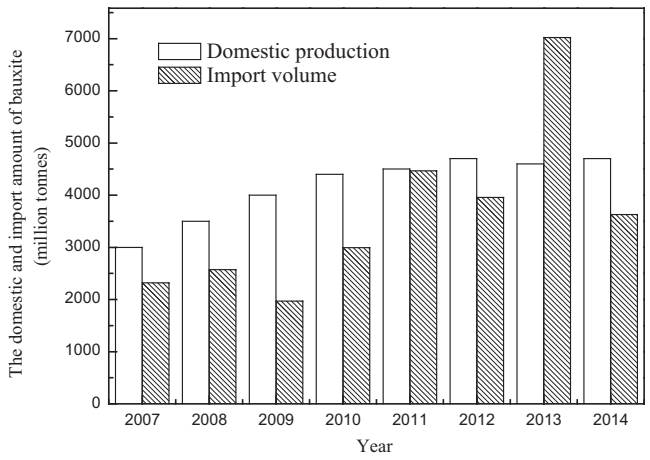

Fig. 2. The domestic and import situation of bauxite in China. Note: Data sourced from website of China's Industrial Information and U.S Geological Survey 2008–2015.

This paper reviews the latest progress in alumina recovery from HAFA. Understanding the chemical and mineralogical properties of coal fly ash is important, as these properties influence its use and disposal. Therefore, the feature of HAFA in China will be introduced firstly. Then an introduction of various technologies of alumina recovery from HAFA and their latest commercial application progress will be given in details, especially the hydro-chemical process. At last, a prospect of recovering alumina from HAFA will be presented as well.

2. Feature of HAFA in China

HAFA was found unexpectedly approximately ten years ago. Due to its high alumina content and the characteristics of the material many researchers and entrepreneurs have been interested in its utilization. Generally, according to the boiler types and burning patterns, fly ash in China can be divided into two categories: pulverized coal (PC) ash and circulating fluidized bed (CFB) ash. Currently, although CFB is characterized as high efficiency, low pollution and clean waste gas, PC boiler still occupies a large proportion (~90%) of China's coal-fired power production. Based on the author's analysis results, the typical chemical compositions of different types of fly ash collected from Inner Mongolia and Shanxi Province in China are listed in Table 1. It can be seen from Table 1, that fly ash mainly contains Al_2O_3, SiO_2, Fe_2O_3, TiO_2, and CaO. The Al_2O_3 content in the two different kinds of HAFA collected from Inner Mongolia are almost both up to 50 wt%, while that from Shanxi province is close to 40 wt%. These concentrations are much higher than the average alumina content in normal fly ash in China, being around 25 wt% (Gao et al., 2007). Moreover, the SiO_2 content in HAFA is relatively low and the ratio of Al_2O_3 to SiO_2 is significantly higher than normal fly ash. The contents of other oxides, such as Fe_2O_3, CaO, MgO, and TiO_2, are also low, at concentrations of <10 wt%. In addition, as a result of desulfurization, through the addition of calcium during combustion in the circulating fluidized bed furnace, the content of CaO in CFB ash is much higher than in PC ash. Since CaO is successfully added as a raw material in alumina production, as a means of removing carbonate salts from the Bayer liquor circuit, the content of CaO in HAFA is not likely to cause detrimental concerns for alumina recovery. In Chinese classification of bauxite, bauxite with Al_2O_3 content of 40 wt% is

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