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Review article

A review of the alumina recovery from coal fly ash, with a focus in China

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ABSTRACT

Coal fly ash, an industrial by-product, is derived from coal combustion in thermal power plants. It is one of the most complex and abundant of anthropogenic materials, and its improper disposal has become an environmental concern and resulted in a waste of recoverable resources. Coal 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, recovering alumina from fly ash has attracted extensive attentions. The present review first describes the alumina recovery history and technologies, and then focuses on the recovery status in China. Finally, the current status of fly ash recycling and directions for future research are considered.

Contents

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1. Introduction

Coal fly ash, a by-product of coal combustion in thermal power plants, is one of the most complex and abundant of anthropogenic materials. It accounts for 5–20 wt.% of feed coal and is typically found in the form of coarse bottom ash and fine fly ash, which represent 70–85 and 15–30 wt.% of the total ash generated, respectively. The generation of coal fly ash is anticipated to increase for many more years, as a result of the world's increasing reliance on coal-fired power generation. A more up-to-date estimate of annual worldwide generation of fly ash is 750 million tonnes [1]. In India, approximately 140 million tonnes is presently generated annually. Total generation in the US and the EU is estimated to be around 115 million tonnes per annum. Fig. 1 shows the generation of coal fly ash in China, from 2001 to 2015. Annual generation is still increasing and is anticipated to reach 580 million tonnes by 2015.

The environmental impact of coal fly ash is now being fully recognized. Most ash disposal methods ultimately lead to the dumping of fly ash on open land. Irregular accumulation and inappropriate disposal of fly ash will lead to its disposal over vast areas of land, with resultant degradation of the soil and danger to both human health and the environment. Fly ash particles are small enough to escape emission control devices, are easily suspended in air and have become a major source of gas pollution. Repeated exposure to fly ash can cause irritation of the eyes, skin, nose, throat and respiratory tract, and can even result in arsenic poisoning. Fly ash can even reach the sub-soil and ultimately cause siltation, clog natural drainage systems and contaminate the ground water with heavy metals. During coal combustion, most of U, Th and their decay products are released from the original coal matrix and are distributed between the gas phase and the solid combustion products.

Recycling coal fly ash can be a good alternative to disposal, and could achieve significant economic and environmental benefits as well. More aggressive efforts have been undertaken recently, to recycle fly ash [2,3]. For example, about 20% of the fly ash generated is being used in concrete production. Other uses include soil amelioration [4–6], ceramic industry [7–9], catalysis and support for catalysis [10–13], adsorbents for removal of various pollutants [14], depth separation [15–17], zeolite synthesis [18–20] and valuable metals recovery [21–23]. The global average utilization rate of fly ash is estimated to be nearly 25% [24]. Current utilization rates have been estimated at 39% for US, 47% for the EU and 15% for India [25,26]. For China, this rate has been increasing annually but has remained around 67% in recent years. It is expected to reach 70% by 2015 (see Fig. 1). However, there is a contradiction in the reported utilization rate in China; Greenpeace reported that the practical utilization rate is only 30% [27]. Whatever the exact figure, it is clear that a significant proportion of coal fly ash will be left untreated and that there is an urgent need for developing new recycling methods for it.

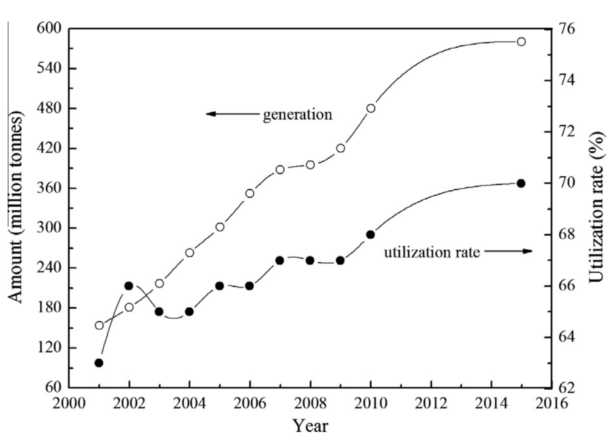

Fig. 1. The generation and utilization of coal fly ash in China.

Understanding the chemical and mineralogical properties of coal fly ash is important, as these properties influence its use and disposal. Coal fly ash is one of the most complex of the materials that can be characterized [28]. The major crystalline phases characterized are mullite and quartz for most ash and major components are metallic oxides with varying contents of unburnt carbon. The contents of principal oxides are, in descending order: $SiO_2 > Al_2O_3 > Fe_2O_3 > CaO > MgO > K_2O$. Coal fly ash is rich in aluminium, making it a potential source of alumina. With the diminishing of bauxite resources as well as the increase in alumina demand, the profitable industrial utilization of coal fly ash in alumina recovery has attracted extensive attentions.

2. Alumina recovery

2.1. History

The recovery of alumina from coal fly ash was pioneered by Grzymek in Poland in the 1950s [29], and was developed mainly because of the bauxite embargo during the Cold War. The recovery process was based on the auto-disintegration of sinter containing calcium aluminates and dicalcium silicate [30]. The sinter was mixed with sodium carbonate and underwent a series of complicated chemical treatments including carbonization and water scrubbing to produce alumina and Portland cement. In 1953, a demonstration plant for recovering 10 thousand tonnes of alumina and producing 100 thousand tonnes of Portland cement was established in Poland. At the end of the 1970s, a second plant was established with the capability of producing 100 thousand tonnes of alumina and 1.2 million tonnes of cement. In the early 1970s, there was widespread concern about an impending producers' cartel of bauxite exporters, leading to higher prices. This concern led the US Bureau of Mines to undertake a major program of research into potential alternatives to bauxite. The processes studied included variations of existing leaching and sintering processes. Since the 1980s, more researches have been conducted and new recovery technologies developed as well.

2.2. Recovery technologies

All commercial production of alumina from bauxite is performed by a process patented by Bayer in 1888 [31]. As bauxite is sufficiently rich in aluminum hydroxide minerals and low in impurities, and the alumina can be extracted relatively easily and inexpensively, any alternate methods for extracting alumina must be economically competitive with the Bayer process. Unlike bauxite, fly ash shows the characteristics of relatively low content of alumina, high content of silica, and the presence of aluminum mainly in the form of chemically stable mullite, which may lead to a low alumina recovery rate and high capital and operating costs. Recently, a number of processes for recovering alumina from coal fly ash have been reported, which can be grouped into three types: the sinter process, the acid leach process and the HiChlor process (see Table 1).

2.2.1. Sinter processes

According to the sintering mediums, the sinter processes can be classified into: lime or lime–soda sinter, the Calsinter process and other sinter processes (e.g. salt-soda sinter, ammonium sulfate sinter and fluorides sinter). The sinter processes involve a high-temperature reaction of coal fly ash with powdered sintering agents to form soluble alumina compounds. The sinter is then leached to separate aluminium, and the pregnant solution is subsequently treated to prepare alumina with high purity.