Current Status and Prospect of Fly Ash Utilization in China

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Abstract:

About 500 million tons (Mt) fly ash produces from coal-fired power stations every year in China, which causes severe economic and environmental problems. In this paper, current status and prospect of fly ash utilization in China was introduced in detail. China is a huge country which has many different geographical environments and various level of economic development. So, the level and method of different area are various. In general, fly ash is mainly used as an additive in concrete and cement in the south of China and thereof little fly ash is piled up, while in the north of China, it can be used as the alumina production material besides the utilization ways mentioned above. As a prospect, high-valued utilization of fly ash is being undertaken, such as producing inorganic fiber or geopolymer.

Keywords: fly ash, utilization, current status, prospect

1.Introduction

Fly ash is an ultrafine solid residue generated from coal fired power plants. It is the largest quantity of industrial solid waste in China. At present, the output of fly ash in China is estimated to be 500 Mt every year[1]. Domestic fly ash discharge is directly related to China's fast development of national economy and its energy structure of primary energy consumption. During the past several years, the Chinese economy remains red-hot with GDP growth rates exceeding 8%. On the other hand, Coal accounts for 68.8% of China's primary energy consumption, which is more than two times of the world average. In the near future, this energy structure cannot change since China is short of nature gas or crude oil[2]. Furthermore, China's coal washing rate is very low currently – only 51% in 2010 – compared to rates of 94.9% in England, 88.7% in France, and 98.2% in Japan, although it is well known that coal washing can greatly reduce the ash production[3].

The quantity of fly ash generated in China is too huge to be completely consumed. It has to be collected in the ash ponds or in the open lands. Some of this ultrafine matter inevitably enters into atmosphere with wind. Usually fly ash can deposit in the nearby 5-10 km environments of the coal fired power plants. Fly ash contains several main elements including

Si, Al, Ca, and Fe, etc, and it also contains some toxic metals such as Cr, Hg, As and Pb, which greatly degrade the soil and enhance the air and water pollution, and ultimately affect the human health[4-5]. So fly ash utilization is seriously emphasized all over the world.

This paper, beginning with the analysis on the current status of fly ash production in China, provides a historical perspective on the fly ash utilization ways developed. Then it gives detailed information on the different ways of fly ash utilization, explaining why the great reduction in fly ash consumption has been achieved and offering guidance for future initiatives. Finally, according to the current status of fly ash utilization and the government's strategic arrangement, it stresses some respects for the future to further strengthen the high-valued use. This paper will prove helpful to the researchers interested in environmental protection, ecological construction and health evaluation for background information.

2 Current Status of fly ash utilization in China

2.1 A brief introduction of fly ash production in China

With the increase of coal consumption in China, the output of fly ash has increased continuously over these years by an annual rate of ~20 Mt, reaching at a level of 480 Mt in 2010, as shown in Fig.1. Now the utilization rate of fly ash in China has also increased greatly, reaching at a higher level of 67% in 2010 – compared to rates of 20% in 1999 and 14% in 1980[6]. But because the quantity of fly ash production is too huge and the by-product of coal-fired plants is mainly concentrated in the north and west of China, where both economic development level and population density are lower than the other area in China, fly ash has been the biggest single solid waste with maximum accumulation of ~ 3.5 billion tons in China. Fortunately, the Chinese government has always attached high importance to fly ash utilization. It adopted a range of major policy measures to strengthen this project. For example, Chinese national Development and Reform Commission stressed in *Implementing Scheme of Mainly Solid Waste Utilization* in 2011 that a level of 75% fly ash utilization rate will be achieved in 2015, and encouraged to develop a technology to produce high-blending fly ash concrete, aerated concrete products, fly ash haydite, etc. to promote the capacities of fly ash utilization in a large scale.

3.2 A detailed introduction of fly ash utilization in China

An additive in cement and concrete. As a large quantity of solid wastes produced from a power plant, fly ash resource-oriented utilization has been concerned by the government and experts concerned. Since the 1950s, fly ash started be used as an additive in cement and concrete. When using as an additive in cement, fly ash can replace some of clay or other alumina-containing materials as raw materials. Besides, fly ash is also be used as mixture to blend with clinker. According to statistics that the fly ash consumption in cement industry accounts for ~38% of total fly ash annual consumption[7]. As for the concrete, based on the morphological effect, active effect and microaggregate effect, fly ash can be used to produce concrete, as is another main utilization way of fly ash. About 48 Mt fly ash is consumed in this field every year, accounting for ~14% of total fly ash annual consumption. Moreover, fly ash can be also used to produce new wall materials, such as brick, aerated concrete block, hollow block, haydite, etc. The consumption in these products contributes to ~26% of total fly ash annual consumption[6].

A raw material for alumina extraction[8]. The main components of fly ash produced in the conventional pulverized coal combustion (PCC) boiler are α-quartz (SiO_2), mullite

($3Al_2O_3 \cdot 2SiO_2$), hematite(Fe_2O_3), and lime (CaO) mainly in the form of spherical particles, while for the ash produced in the advanced circulating fluidized bed combustion (PCC) boiler they are amorphous silica (SiO_2) and alumina (Al_2O_3), mullite ($3Al_2O_3 \cdot 2SiO_2$), hematite(Fe_2O_3), lime (CaO), and gypsum ($CaSO_4 \cdot 2H_2O$) with irregular particle shape. It is estimated that 10 per cent of total fly ash in China contains alumina higher than 30% and is considered to be otherwise a scare alternative of bauxite[9], since there is not enough bauxite in China. Thereby, extraction of alumina from fly ash have been the research focus in the last several years and two typical methods have been proposed by many researchers, one is called Acid Process and the other is called Base Process.

In the acid leaching process, only fly ash produced in PCC boilers can be treated well. It first reacts with hydrochloride or sulfate solution to produce aluminum chloride or aluminum sulfate. Then the salts containing aluminum is separated from the acid medium and subsequently decomposed. This kind of acidic process inevitably causes serious equipment corrosion because of acid usage. In addition, the impurities of iron oxide and calcium oxide, etc, are difficult to be removed from the leaching solution. So, the acid leaching process is difficult to produce high quality alumina. But in recent years the acid process arouses a great interest by its lower reaction temperature - about 130 ^oC - and therefore a lower production cost. Now a pilot project has been built and even attained a alumina recovery rate of more than 80% under the condition of continuous running of 150 d.

Base Process includes sintering method and hydro-chemical process. They are all characterized by high alumina recovery rate (~85%), high grade alumina product and recyclable reaction medium, and also show favorable application value and potential prospect. The disadvantages, however, is higher reaction temperature (~1300 ^oC for sintering method and ~300 ^oC for hydro-chemical process) and therefore a higher production cost. Additionally, the abundant slag contains 2-4% Na_2O, which is very difficult to be reused. Even so, a demonstration project for the sintering method has been built for seven years, and a demonstration project for the hydro-chemical process is being built. The related researchers are conducting to develop a new technology to use the slag with some alkaline.

In the Base Process, pre-desilication treatment is often adopted to remove the active silica in the fly ash by sodium hydroxide solution in order to increase the alumina content and decrease the total material flow in the system. Subsequently, the removed silica is transformed into silica white via carbon dioxide decomposition method or calcium silicate via calcium oxide precipitation method. So another by- product of silica white or calcium oxide is produced during the alumina extraction in the basic process.

For all that, the research on the high-valued utilization of fly ash is still in its early stage, and there are many questions eager to solve both in theory and practice.

Other ways for fly ash utilization. Fly ash can also be in the fields of road building, backfilling of pile well, soil improvement, absorbent and so on. China has made large progress in the applications of fly ash in these aspects, contributing to ~20% of total fly ash annual consumption[6].

4 A prospect of fly ash utilization

4.1 Production of inorganic fiber

In order to increase the added value of fly ash products, it is an important and attractive choice to convert fly ash into inorganic fiber. There are two methods to produce such fiber:

one is called direct method, and the other is called indirect method. In the direct method, fly ash is heated to a high temperature of ~1600^{o}C to be molten. Then the melting magma is cooled by high-pressure energetic gas in the vertical direction of magma flow. Thus an ultrafine fiber with a 3-6μm diameter can be produced[10]. This method has some shortcomings such as high energy consumption and difficult equipment manufacturing. The research on fly ash applications to produce inorganic fiber has a long history, but it remains still in laboratory or pilot-plant scale, without industrialization. While in the indirect method illustrated in Fig.2, which was developed by a laboratory in the Institute of Process Engineering, Chinese Academy of Sciences, fly ash is first chemically treated to extract the alumina in the fly ash at a moderate temperature (far less than 1600 ^{o}C). The produced slag is then treated in an alkaline solution with the action of a kind of inorganic crystalline control agent and transformed into the fiber products, as can be clearly seen from Fig.3.

This fiber product is tested by compression molding machine and shows an excellent physical properties. Fig.4 shows a picture of a cylindrical testing sample with 25 mm diameter and 30 mm height. When the bulk density of the sample is 212 kg/m^3, its compressive strength can reach at a level of 13.23 MPa – a very desirable value – with a heat conductivity of 0.056 W/(m·k), as suggests that this fiber product can be used as an advanced heat insulating material and also an anti-flammable wall materials since there is no organic matter in the fiber product.

Additionally, this inorganic fiber has a potential application in papermaking industry and rubber or plastic industry as fillers. The research on this field is undergoing in the laboratory. The preliminary experimental results shows a good application future in corrugated paper making.

4.2 Production of geopolymer

The name of Geopolymer was first proposed by an French professor in 1978, which is a kind of inorganic compounds containing AlO_4 and SiO_4 connected each other in a hollow net structure. It is characterized by good mechanic properties, high strength on the early stage, excellent absorption capacities for almost all toxic metal ions, low energy consumption and carbon dioxide emission, etc. So it is popular in engineering application. Presently, This new polymer has been being studied in the special research institutes in more 30 countries all over the world[11-13].

In China, it is a hot point to synthesize geopolymer by using fly ash as main raw materials in the last several years. Now the research contents mainly focus on the effect of fly ash activators kind and quantity and curing process on the material properties, as well as the aggregation mechanism of key iron clusters AlO_4 and SiO_4. There have been made great progress in this field. However, the problem of too short beginning setting time has not solved yet. Moreover, if alkali aggregate reaction occurs during the application of geopolymer, and if yes, how to avoid it remain unknown.

5 Conclusion

China has taken many measures to solve the problems in fly ash pollution to address the challenge of a great amount of fly ash production every year and its huge accumulation. Now fly ash utilization rate has reached at a level of 68% in China. It is primarily used as an additive in concrete and cement in the south of China and also used as the alumina production material besides the utilization ways aforementioned in the north of China. Now, high-valued utilization of fly ash is being undertaken, such as producing inorganic fibre or geopolymer, and has showed a promising prospect.

Conference

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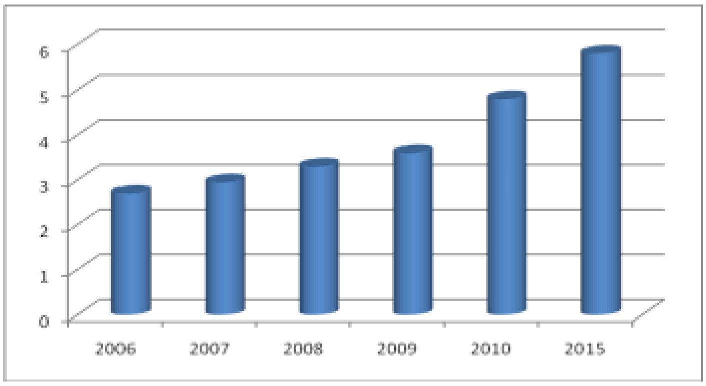

Fig. 1 Annual emission of fly ash in China

Note: the emission of fly ash in 2015 in Ref. 1 was cited here

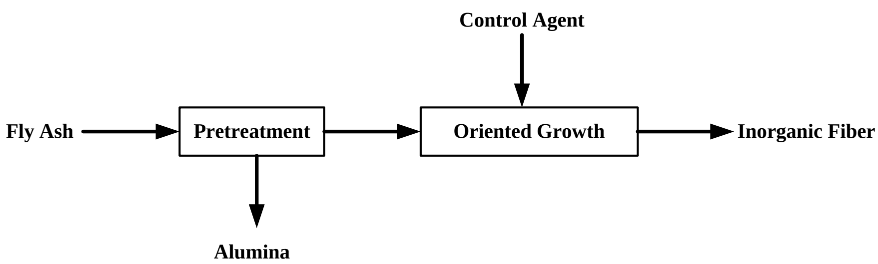

Fig. 2 Technical route of indirect method

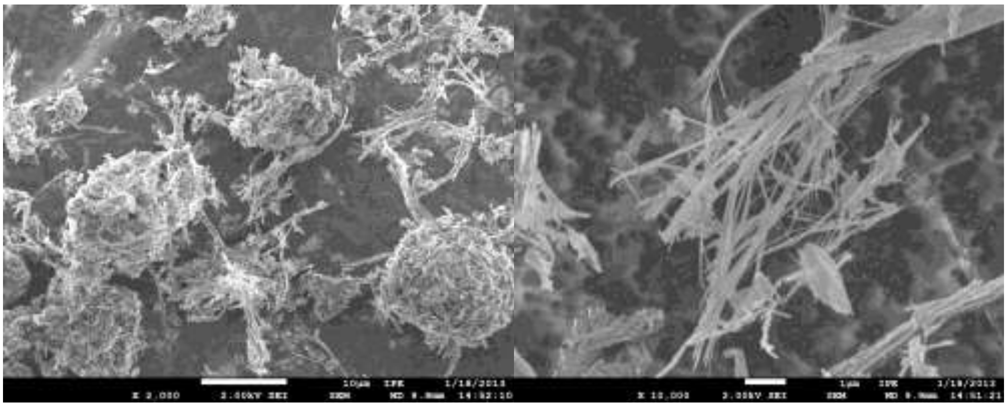

Fig. 3 SEM of produced inorganic fiber

Fig. 4 The picture of cylindrical sample