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A review on the management of municipal solid waste fly ash in American

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Abstract

With the accelerating process of urbanization, the amount of municipal solid waste (MSW) generation increases continuously. Landfill occupies a lot of land resources, leading several cities run into a condition being surrounded by MSW. In recent years, MSW incineration rises gradually. Incineration can reduce the MSW volume by 85%~90% and the mass by about 80%, and incineration with energy recovery is one of the several waste-to-energy (WtE) technologies [1-3]. However, municipal solid waste incineration fly ash, byproducts of MSW incineration, contains large amounts of heavy metals and dioxins, improper disposal will cause serious environmental and human health hazards. This review summarizes the MSW incineration fly ash management system and related policies and regulations in United States, as well as the main disposal methods and utilization technology, in order to provide reference for the management of MSW incineration fly ash in China.

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Keywords: Municaipla solid waste; Incineration; Fly ash; Waste disposal ; Waste utilization

1. Introduction

Waste incineration was proposed by the Americans in 1901. With such features as small floor area, harmlessness, quantity reduction, effective recycle and prolong the service life of the landfill, incineration can eliminate a large number of MSW continuously, stably, safely and reliably, which makes incineration become one of the important

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MSW harmless treatment methods. MSW incineration (MSWI) produces two main types of ash, which can be grouped as bottom ashes (BA) and fly ashes (FA). MSWI fly ash is the residue collecting from flue gas purification system of waste incineration power plant, and most of them contain heavy metals, dioxin and other characteristic pollutants, so in some countries the fly ash can be considered to hazardous waste. Fly ash is generally considered higher potential risk than bottom ash, because the fly ash comprises higher concentration of heavy metals.

MSW incineration started in late 1980's in China. According to the "12th Five Year Plan", the daily processing capacity of MSW incineration in China will be increased from 0.896 million tonne/d in 2010 to 3.072 million tonne/d in 2015. The mass of fly ash will reduce to 1%~6% of MSW after incineration, so according to this ratio, the MSWI fly ash production will reach 1 million tonne/y to 6 million tonne/y during the "12th Five Year Plan" period. In China, MSW is commonly burned unsorted. MSW entering an incinerator may contain kitchen waste, wood, paper, glass, construction waste and all kinds of plastic, etc. Unsorted kitchen waste, wood and PVC may cause high concentrations of Na, K and Cl in fly ash [4, 5].According to solubility, fly ash composition can be divided into soluble substances (salt) and insoluble substances (slag). The main components of soluble substances are harmful salts to cement kiln calcination, such as Na, K, Cl, etc. The remaining 70% of fly ash are insoluble substances, which contain calcium, silicon, aluminum, iron and other cement ingredients.

MSWI fly ash has great harm to the environment and human health. With the decrease of the landfill site, the harmless treatment and utilization of MSWI fly ash has been drawn more and more attention by the government and researchers. Although the MSWI fly ash contain high concentrations of pollutants like heavy metals, slats, chloride and organic waste, there are still many utilization methods successfully used in developed countries. This paper summarized the management practice of MSWI fly ash in United States, including current regulations, disposal methods and utilization technology.

2. Regulations related to MSWI fly ash in United States

The Resource Conservation and Recovery Act (RCRA) is the nation's primary law governing the disposal of solid and hazardous waste in Untied States. The hazardous waste management, under Subtitles C of RCRA, established a system for controlling hazardous waste from "cradle to grave". The RCRA regulations governing hazardous waste identification, classification, generation, management and disposal are set forth in different parts of title 40 of the Code of Federal Regulations (CFR). The following table indicates where the RCRA regulations appear in the Code of Federal Regulations.

Table 1. RCRA Subtitles C regulations appear in the Code of Federal Regulations

Section of RCRA	Coverage	Final regulation
Subtitle C	Overview and definitions	40 CFR part 260
3001	Identification and listing of hazardous waste	40 CFR part 261
3002	Generators of hazardous waste	40 CFR part 262
3003	Transporters of hazardous waste	40 CFR part 263
3004	Standards for HWM facilities	40 CFR parts 264, 265, 266, and 267
3005	Permit requirements for HWM facilities	40 CFR parts 270 and 124
3006	Guidelines for State programs	40 CFR part 271
3010	Preliminary notification of HWM activity	(public notice) 45 FR 12746 February 26, 1980

Title 40-Protction of the Environment arranges mainly environmental regulations that were promulgated by the US Environmental Protection Agency (EPA). According to 40CFR 260.10, generator is "any person, by site, whose act or process produces hazardous waste identified or listed in part 261 of this chapter or whose act first causes a hazardous waste to become subject to regulation." 40CFR 262 required that a person who generates a solid waste must determine if the waste is a hazardous waste and supervise the final disposal of the waste. Once the waste is identified as hazardous waste, which is defined in RCRA, it becomes the management objective, and the generators will be responsible for the management. The generators are required to ensure and demonstrate that the hazardous waste is properly identified, managed and disposed before recovery and disposal. Generators of hazardous waste are regulated based on the amount of hazardous waste they generate in a calendar month.

RCRA Subtitles C Section 3001 required EPA to “develop and promulgate criteria for identifying the characteristics of hazardous waste, and for listing hazardous waste, which should be subject to the provisions of this subtitle, taking into account toxicity, persistence, and degradability in nature, potential for accumulation in tissue, and other related factors such as flammability, corrosiveness, and other hazardous characteristics”. According to RCRA, MSWI ashes are required to pass the Toxicity Characteristic Leaching Procedure (TCLP) to be considered as non-hazardous waste. MSWI fly ash often fails TCLP.

The starting point of hazardous waste management in United States is to reduce waste generation and improve the recycling rate, so as to reduce the amount of waste into environment and to be treated. The treatment, storage and disposal of hazardous waste is clearly defined in United States. Treatment method refers to the processes that can realize recycle, reuse or reduce by changing the property and composition of waste (e.g. incineration). Disposal method refers to the permanent preservation processes such as landfill. In addition, the United States emphasizes to meet the technical requirements and emission standards, rather than mandatory of technology.

According to 40CFR, hazardous waste generators are divided into large quantity generator, small quantity generator and exempt small quantity generator. Large quantity generator (LQ Gs) refers to the one accumulates 1,000 kilograms or greater of any “hazardous waste” as identified or listed in 40 CFR part 261 in one month. Small quantity generator (SQ Gs) refers to the one accumulates greater than 100 kg and less than 1000 kg of hazardous waste in a calendar month, such as laboratories, printing shops and dry cleaners. Generator accumulates less than 100 kg of hazardous waste in a calendar month are exempt small quantity generator, who undertaken smaller obligations . Tracking and licensing are two management program of hazardous waste in United States. Each enterprise related to hazardous waste (LQ Gs and treatment enterprise) are required to get the EPA identification number from the Administrator, and RCRA requires a permit for the “treatment,” “storage,” and “disposal” of any “hazardous waste” as identified or listed in 40 CFR part 261. In order to track the generation and transfer of hazardous waste, EPA requires LQ Gs and SQ Gs to prepare a manifest and keep a copy of each manifest. According to 40CFR, the copy of each manifest must keep for three years.

3. Disposal technology of MSW fly ash

To handle MSWI fly ash, different methods have been proposed. At present, separation processes, solidification/stabilization and thermal methods are three main techniques. In practice, it is common to start the treatment of ash with separation processes, followed by solidification/stabilization or thermal methods.

3.1. Separation processes

Separation processes aim to reduce the chloride, salts, alkali and heavy metals in MSWI fly ash and improve the quality of MSWI fly ash. Water washing is a feasible method to remove chloride and salts from ash, and this method is relatively economical and environmentally friendly. However, one drawback is that large amount of heavy metals will be released with the soluble salts. In order to protect the environment more effectively, the heavy metals in fly ash can be extracted and recovered. The main methods include acid extraction, alkali extraction, high temperature extraction, biological extraction and so on. The fly ash and extracted heavy metals can be used for resource utilization respectively. The extraction technology of heavy metals mainly has the following advantages: 1) the soluble salt in the ash is dissolved in water, which improves the treatment effect, and increases the stability of the process; 2) the dehydrated soluble salt in treated product is few, which is easy to transportation and landfill; 3) the process is simple and easy to operate. In order to recover the heavy metals, their concentration must be high to ensure recovery. The leaching of heavy metals depends on the type of extraction solvent, the pH, as well as the liquid-to-solid ratio

3.2. Solidification/Stabilization (S/S) Methods

Solidification/Stabilization (S/S) treatment technology is one of the international main methods at present, refers to those technologies that use additive or binder to immobilize the hazardous content present in MSWI fly ash before landfill disposal or utilization. Generally, the solubility, leachability and toxicity of MSWI fly ash will reduce after S/S treatment. According to "Standard for Pollution Control on the Landfill Site of Municipal Solid Waste" (GB 16889-2008), MSWI fly ash can go to sanitary landfills after it is treated and meets the heavy metals leaching toxicity criteria.

- C**ement solidification**

Among the different available S/S technologies, cement-based processes are still most widely used in hazardous waste treatment due to the good treatment effect, relatively low treatment costs and easy to application. During cement solidification process, in order to reduce leachability and its environmental impact in the final disposal, MSWI fly ash and cement are mixed with water in an appropriate proportion, hazardous content like heavy metals in MSWI fly ash will be immobilized after cement hydration reaction. [6-8] According to the character of MSWI fly ash, the addition of different type hydraulic binders can improve the cement solidification effect. [9-10]

USEPA has regarded cement solidification technology as the best technology of hazardous waste treatment. However, the drawback of this process is that the volume of fly ash will be increased (almost doubled) using this method. Also, the adverse effects caused by heavy metals and soluble salts (such as chlorides and sulphates) in fly ash will disturb the normal hydration process of cement and reduce the strength of cement solidified waste form. Slow release of heavy metals from the treated fly ash was found in a wet environment, thus making it still hazardous to the environment.

- **Chemical stabilization**

Through adding chemical stabilizers, chemical stabilization technology can change the physical and chemical properties of MSWI fly ash. The existing forms of heavy metals in MSWI fly ash are changed by pH control, precipitation and adsorption, in order to reduce bioavailability and mobility of metals, and realize stabilization. Compared with cement solidification, the mass and volume of MSWI fly ash will not change a lot through chemical stabilization. Currently there are many types of chemical stabilizers for MSWI fly ash, which can divided into two groups: organic and inorganic. The most commonly used stabilizing agents are: gypsum, phosphate, bleach, sulfides (sodium thiosulfate, sodium sulfide) and polymer organic stabilizers.

3.3. Thermal Methods

Thermal methods can be divided into three major categories: vitrification, sintering and fusion. Vitrification is a chemical process whereby a mixture of glass precursor materials and hazardous waste are melted or fused at high temperatures to generate an amorphous, single phase product. Sintering is a chemical process whereby a mixture of hazardous waste and small glassy are melted at high temperature in 1000-1100 ℃ to get a glass waste form. Fusion is a chemical process whereby MSWI fly ash are melted or fused at high temperature over 13100 ℃ in fuel furnace to form either a crystalline or heterogeneous product. During the fusion process, organic pollutants such as dioxins in fly ash can be decomposed, burned and gasification, while the inorganic pollutants are melted to glassy slag. Heavy metals residue in the fly ash are surrounded by a sintered glassy network structure, which effectively control the leaching of heavy metals. This method can reduce the volume of waste by 60% or more, and the products are resistant to leaching, which can be used as building materials or raw materials for production of glass, ceramics. The technology is now recognized as one of the most stable and safety methods, with advantages such as high volume reduction rate, stable slag, and non-leaching of heavy metals. [12-14] Due to the significant advantage of volume reduction, fusion technology for fly ash treatment developed rapidly in the United States.

4. Utilizations of MSWI ash in United States

The major uses of fly ash are cement and concrete, road pavement, agriculture (fertilizer), and other applications (adsorbents and sludge conditioner). Different from Europe, in the U.S., bottom ash and fly ash are mixed together and not segregated. BA and combined ash used as hot mix asphalt, cement and concrete, and landfill cover in the U.S. are summarized.

4.1. Hot Mix Asphalt

After screening, magnetic separation, ferrous and nonferrous metals are removed from mixed ash or BA. Mixed ash or BA with appropriate particle size can be mixed with other aggregates, used as a mixture of asphalt pavement. This approach is used in the United States, Japan, and some European countries.

From the 1970s to the early 1980s, the US Federal Highway Administration (FHWA) had successfully completed at least six asphalt pavement demonstration projects using mix ash in cities like Houston, Washington and Philadelphia. These ashes are used in the adhesive layer, the wear layer/surface layer and the roadbed of the road. The results showed that when used in the adhesive layer or roadbed, the best ash content was no more than 20%; used in the wear layer/surface layer, the best ash content was not exceed 15%. Also, the demonstration project indicated that, as long as proper handling, ash used as asphalt will not cause environmental pollution.

4.2. Cement and concrete

Fly ash contains large amounts of SiO_2, $A1_2O_3$ and CaO, its composition is very similar to the composition of raw materials foe cement production. Therefore, fly ash could be a possible replacement of raw material in cement production. If fly ash added to production of cement without pretreated, the high levels of heavy metals and chloride in fly ash will affect the product quality. And the heavy metals will also be an environmental concern. Studies showed that, washing pre-treatment of fly ash to reduce water-soluble substances like chloride before cement curing, will greatly enhance the compressive strength and reduce the leaching toxicity of the products. Based on S/S technology, fly ash can be potentially applied as a replacement of cement or as an aggregate, but the quantities of fly ash added to the process should be carefully controlled in order to ensure the process safety as well as product quality. [15]

In the United States and the Netherlands, bottom ash (or mixed ash) is used as a partial substitute aggregate for concrete. The most common is mixing the bottom ash, water, cement and other aggregates to make concrete blocks by a certain percentage, which has been commercialized in the United States. Processed after ferrous recovery and screened to size, stabilized BA and combined ash (85% ash and 15% type II Portland cement) used in masonry blocks and artificial reef by Waste Management Institution of Marine Scientific Research Center in Stony Brook University in Long Island Sound seabed. The result shows that the blocks were stronger than original concrete blocks, and there is no ground or water pollution during six years.

4.3. Landfill Cover

Landfill sites have environmental protection facilities such as barrier layer and leachate recovery system, the adverse effects on human health and environment caused by heavy metal leaching from ash can be well controlled. The pretreatment process for ash such as screening, magnetic separation and particle size distribution is unnecessary if used as landfill cover. Therefore, in consideration of economy, environment and technology, ash used as landfill cover material is a very good choice. Combined ash used as landfill cover at landfill in Honolulu, Hawaii showed very well performance.

5. Conclusions

Unlike many countries, BA and FA in U.S. are combined to be disposed as combined ash. There is no proper Federal regulations and guidance for MSWI fly ash management and disposal in U.S. Pre-treatment is necessary before ash utilization. The main utilization of ash in U.S. are hot mix asphalt, cement and concrete, and landfill cover. Existing research and engineering practice shows that the utilization of ash is feasible, and if proper management, use of ash will not cause environment pollution.

References

1. Liu S M. Harmless Disposal and Incineration Facilities for Solid Wastes. *Power Equipment* 2008; (2): 35-39.
2. http://www.gov.cn/gongbao/content/2012/content_2137639.htm

3. Yan W P, Chen Y Y. Study on slagging characteristics of biomass fuels. *Journal of North China Electric Power University* 2007; 34(1): 49-54.
4. Yu J, Yu Q, Li M J, et al., Removal of toxic and alkali/alkaline earth metals during co-thermal treatment of two types of MSWI fly ashes in China. *Waste Management* 2015; 46: 287-297.
5. Tortosa Masiá, A. A., B. J. P. Buhre, R. P. Gupta, et al., Characterising ash of biomass and waste. *Fuel Processing Technology* 2007; 88(11–12): 1071-1081.
6. Liu X R. Discussion on current treatment and disposal technology situation of MSW fly ash in our country. *Engineering construction* 2014; 46(6):56-60
7. Rémond, S., P. Pimienta, and D. P. Bentz, Effects of the incorporation of Municipal Solid Waste Incineration fly ash in cement pastes and mortars: I. Experimental study. [J] Cement and Concrete Research, 2002, 32(2): 303-311.
8. Collivignarelli, Carlo and Sabrina Sorlini, Reuse of municipal solid wastes incineration fly ashes in concrete mixtures. [J] Waste Management, 2002, 22(8): 909-912.
9. Polettini, A., R. Pomi, P. Sirini, et al., Properties of Portland cement — stabilised MSWI fly ashes. [J] Journal of Hazardous Materials, 2001, 88(1): 123-138.
10. Mangialardi, T., A. E. Paolini, A. Polettini, et al., Optimization of the solidification/stabilization process of MSW fly ash in cementitious matrices. [J] Journal of Hazardous Materials, 1999, 70(1–2): 53-70.
11. Quina, Margarida J., João C. Bordado, and Rosa M. Quinta-Ferreira, Treatment and use of air pollution control residues from MSW incineration: An overview. [J] Waste Management, 2008, 28(11): 2097-2121.
12. Haugsten, Kjell E. and Bengt Gustavson, Environmental properties of vitrified fly ash from hazardous and municipal waste incineration. [J] Waste Management, 2000, 20(2–3): 167-176.
13. Sakai, Shin-ichi and Masakatsu Hiraoka, Municipal solid waste incinerator residue recycling by thermal processes. [J] Waste Management, 2000, 20(2–3): 249-258.
14. Sørensen, M. A., E. P. B. Mogensen, K. Lundtorp, et al., High temperature co-treatment of bottom ash and stabilized fly ashes from waste incineration. [J] Waste Management, 2001, 21(6): 555-562.
15. Charles H. K. Lam, Alvin W. M. Ip, John Patrick Barford and Gordon McKay. Use of Incineration MSW Ash: A Review. Sustainability 2010, 2, 1943-1968