Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Achieving zero waste of municipal incinerator fly ash by melting in electric arc furnaces while steelmaking

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ARTICLE INFO

Article history:
Received 17 May 2016
Revised 16 February 2017
Accepted 17 February 2017
Available online xxxx

Keywords:
Electric arc furnace
Municipal incinerator fly ash
Melting
Steelmaking by-products
Zero waste
Zero landfill
Total recycling

ABSTRACT

The main objective of this work was to promote zero waste of municipal incinerator fly ash (MIFA) by full-scale melting in electric arc furnaces (EAFs) of steel mini mills around the world. MIFA, generally, is considered as a hazardous waste. Like in many countries, MIFA in Taiwan is first solidified/stabilized and then landfilled. Due to the scarcity of landfill space, the cost of landfilling increases markedly year by year in Taiwan. This paper presents satisfactory results of treating several hundred tons of MIFA in a full-scale steel mini mill using the approach of "melting MIFA while EAF steelmaking", which is somewhat similar to "molten salt oxidation" process. It was found that this practice yielded many advantages such as (1) about 18 wt% of quicklime requirement in EAF steelmaking can be substituted by the lime materials contained in MIFA; (2) MIFA would totally end up as a material in fractions of recyclable EAF dust, oxidized slag and reduced slag; (3) no waste is needed for landfilling; and (4) a capital cost saving through the employment of existing EAFs in steel mini mills instead of building new melting plants for the treatment of MIFA. Thus, it is technically feasible to achieve zero waste of MIFA by the practice of this innovative melting technology.

1. Introduction

Nowadays, waste prevention or waste reduction in the first place is prioritized over other options in the hierarchy of waste management. Recovery of materials and energy (e.g., waste-to-energy) comes as the second and third options. Then, intermediate treatment other than incineration follows. Landfilling of waste is the final option to be considered. However, according to the Zero Waste Alliance (2016), "Zero Waste" includes: (1) zero waste of resources, (2) zero waste in production activities, (3) zero waste in product life, (4) zero emissions, and (5) zero use of toxics.

Over the past four decades or so, the incineration technology for municipal solid waste (MSW) has been greatly developed. Today, incineration of municipal solid waste is an already proven and bankable technology in many countries such as UK (UK Department for Environment, Food and Rural Affairs, 2013). A modern incineration technology, generally, has several advantages including mass reduction (ca. 70%) and volume reduction (up to 90%) of waste (Lam et al., 2010), waste-to-energy, and so on. However, noncombustible components in MSW would end up becoming bottom ash, whereas the particulate matter emitted from combustion (known as fly ash) is captured by air pollution control devices. In general, flue gas generated from the waste-to-energy facilities contains acidic gases such as hydrogen chloride, sulfur dioxide and nitrogen oxides. Thus, calcium oxide (quicklime) or calcium hydroxide (hydrated lime) is often used to neutralize such acidic gases. The fly ash fraction, including "reaction products" resulted from the above-indicated semidry lime scrubbing process, is of concern in this work. It is termed as "municipal incinerator fly ash" (MIFA) in this paper. In Taiwan, currently, there are 24 large-scale MSW incinerators in operation. Many of these MSW incinerators simultaneously treat both MSW (i.e., household garbage) and non-hazardous industrial waste. According to the statistical data of the Environmental Protection Administration (EPA) of Taiwan, about 4,329,863 metric tons of MSW and about 2,292,207 metric tons of non-hazardous industrial waste were incinerated generating about 304,461 metric tons of MIFA in 2015. In other words, over 800 metric tons of MIFA was generated per day in Taiwan.

In many countries around the world, MIFA is categorized and regulated as a hazardous waste because generally it contains heavy metals (e.g., Pb, Cr, and Hg) and polychlorinated dibenzo-p-dioxins/polychlorinated dibenzofurans (PCDD/Fs, or simply dioxins/furans) (Liu et al., 2015). This waste is also regulated by the Basel Convention, which restricts transboundary movements

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http://dx.doi.org/10.1016/j.wasman.2017.02.021
0956-053X/

of hazardous wastes and their disposal among nations (Secretariat of the Basel Convention, 2011). In the literature, many studies have been conducted aiming at recycling of MIFA (Lam et al., 2010). In practice, however, MIFA is treated by monofilling (Hjelmar, 1996; Ecke, 2001), monofilling with a prior treatment of solidification/stabilization (Yang and Chen, 1994, 1996; Yang et al., 1998; Ecke, 2001), and melting (Sakaia and Hiraoka, 2000; Ecke, 2001; Ho, 2002; Nishino et al., 2009). To be in accordance with the regulations, MIFA is being treated by cement solidification prior to monofilling in Taiwan. The only exception occurred during 2002–2004 when hundreds of tons of MFA were tested by melting in an electric arc furnace (EAF) while making steel. In general, the technology "Melting MIFA while EAF steelmaking" has the merits of volume reduction, detoxification, and resource recycling for MIFA. According to Ho (2002), commercial-scale melting of MIFA has been practiced in about 80 Japanese plants for the treatment of MSWI ashes, with less than 10 plants solely for MIFA. Among various commercial types of ash-melting furnaces (Sakaia and Hiraoka, 2000), electric resistance furnace, electric arc furnace, and plasma furnace seem to gain higher market shares (Ho, 2002; Nishino et al., 2009).

According to Hjelmar (1996), acid gas scrubbing residues from dry/semidry process (including fly ash) contained 170–290 mg/kg of calcium. However, results of preliminary studies by the present author's group have revealed that MIFA contains about 30–40 wt% of lime materials resulting from the injection of calcium hydroxide slurry into the semidry scrubbers for air pollution control in MSW incineration plants in Taiwan. In steelmaking, generally, high slag basicity (i.e., high lime content) is beneficial for phosphorus removal during the melting period. Thus, quicklime (CaO) is required and charged as a raw material into an EAF. Hypothetically, by injecting MIFA into the molten iron/steel while steelmaking, the lime materials therein could be used as a substitute for quicklime required. In the meantime, supposedly, the inorganic constituents of MIFA would mostly become the slag components (i.e., EAF slag and ladle furnace slag) and EAF dust after EAF steelmaking unless otherwise fugitive in the atmosphere. In normal EAF steelmaking, both EAF slag and LF slag (ladle furnace slag) are categorized as nonhazardous, recyclable materials in Taiwan. On the other hand, EAF dust is categorized as hazardous, but generally recyclable.

Molten salt oxidation (MSO) process is a non-flame, thermal process that is capable of destroying all organic materials (e.g., polychlorinated biphenyls) while simultaneously retaining inorganic and hazardous components in the melt. MSO process was developed several decades ago by Rockwell International, now part of the Boeing Company. This treatment process, however, is not known to many researchers in the field of hazardous waste treatment/management. Recently, MSO history, design, and engineering details have been reviewed by Yao et al. (2011). Based on the similar concept, the present authors developed the novel technology of "melting MIFA while EAF steelmaking". Briefly, it is to inject MIFA into the molten iron/steel to destroy dioxins/furans and other organic materials contained in MIFA and simultaneously retained inorganic substance in the melt, which would eventually become constituents of steelmaking slags and dust. Thus, this melting technology is absolutely not a physical dilution or dispersion process.

During 2002–2004, several hundred tons of MIFA have been treated in a full-scale steel mini mill by the present authors using the approach of "melting MIFA while EAF steelmaking". However, during 2006–2014 the steel price increased and remained high for several years due to a high demand of steel worldwide. In addition, since "melting MIFA while EAF steelmaking" is not the core business for an EAF steelmaking plant, the EAF steelmaking plant having such a melting MIFA experience showed no further interest in the implementation of this novel melting technology for MIFA. During the past 2–3 years the global steel sector has faced its worst recession in a decade. Implementation of this novel technology of "melting MIFA while EAF steelmaking" becomes beneficial to the EAF steelmaking plants because by collecting MIFA treatment fee for melting MIFA in EAF steelmaking operations could yield a remarkable extra income for the EAF steelmaking plants. Though the aforementioned melting technology for MIFA had been developed more than a decade ago, however, its merits have not been reported in any scientific journal before. Presumably, it is a good time now to promote the novel technology of "melting MIFA while EAF steelmaking" and present more details about this technology to the academia and steel industry. Thus, the objectives of this work are threefold: (1) to assess the technical feasibility of injecting MIFA into the molten iron/steel for melting treatment while EAF steelmaking; (2) to find out whether EAF dust, EAF slag and LF slag resulted from melting MIFA in a full-scale steelmaking EAF are nonhazardous and recyclable; and (3) to find out if the goal of "zero waste of MIFA" is achievable via "melting MIFA while EAF steelmaking".

2. Materials and methods

2.1. Materials

In this work, MIFA samples were collected from two different large-scale MSW incineration plants in Taiwan (designated MSWI-1 and MSWI-2, respectively). The designed treatment capacities for MSWI-1 and MSWI-2 are 1350 metric tons per day and 900 metric tons per day, respectively. Both MSW incineration plants employ $Ca(OH)_2$ slurry in their semidry scrubbers for the control of acid flue gases and collection of emitted particulate matter. The MIFA samples collected from MSWI-1 and MSWI-2 were characterized before melting.

2.2. Methods

2.2.1. Technology concept for melting MIFA in a steelmaking EAF

In this work the method and procedures used for melting MIFA in a steelmaking EAF are presented in Fig. 1. [Detailed description of EAF steelmaking operations can be found elsewhere (American Iron and Steel Institute, 2016)] According to Huang (2005), the melt flow points for MIFA samples collected from MSWI-1 and MSWI-2 were determined to be 1594 °C and 1333 °C, respectively. Thus, the injected MIFA samples could be melted by the molten iron in the EAF, which is normally operated at a temperature ranging from 1630 °C to 1730 °C. The underlying concept of this practice is using the high temperature of molten iron to melt MIFA so that the contained organic pollutants (e.g., dioxins/furans) could be destructed. The realization of the hypothesis is attainable. According to Dioxin Facts Org. (2017), complete destruction of dioxins and furans and their chemical "building blocks" in waste material during combustion can be achieved through the "3-T Rule": (a) high combustion **Temperature** to maximize waste destruction; (b) adequate combustion **Time** (usually two seconds) to maximize waste destruction; and (c) high combustion **Turbulence** to distribute heat evenly and ensure complete waste destruction. The regulation set by Taiwan Environmental Protection Administration (Taiwan EPA, 2006) also requires that at least 1000 °C must be maintained at the central part of the exit of the combustion chamber and a minimum of 2-s residence time to burn the flue gas to yield a destruction and removal efficiency of greater than 99.999% for dioxins and furans. In addition to the complete destruction of organic pollutants, the lime material contained in MIFA can be reutilized to partially substitute quicklime required for EAF steelmaking. The noncombustible component in MIFA would become parts of EAF dust, EAF slag and LF slag.