Environmental Pollution 158 (2010) 2809–2814

Contents lists available at ScienceDirect

Environmental Pollution

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

Commentary

Curbing dioxin emissions from municipal solid waste incineration in China: Re-thinking about management policies and practices

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The management policies and practices need to be improved to curb the increasing dioxin releases from municipal solid waste incineration in China.

A R T I C L E I N F O

Article history:
Received 25 February 2010
Received in revised form
23 May 2010
Accepted 12 June 2010

Keywords:
Dioxins
Municipal solid waste
Incineration
Management policies and practices
Waste reduction

A B S T R A C T

As one of the countries with large amounts of dioxin releases, the control of dioxins is a major challenge for China. Municipal solid waste (MSW) incineration should be considered a high priority source of dioxin emissions because it is playing an increasingly more important role in waste management. MSW incineration in China has much higher emission rates of dioxins than in the developed countries, partially resulting from the gaps in the technologies of incineration and flue gas cleaning. Moreover, the current management policies and practices also contribute significantly to the problem. We recommend lowering dioxin emission standard, strengthening fly ash management, and improving regulation enforcement to reduce dioxin releases into the environment from MSW incineration. We also propose that alternative strategies should be considered on dioxin control and call for an expansion of economic instruments in waste management to reduce waste generation and thus the need for incineration.

1. Dioxin contamination in China

“Dioxins” refer to a family of related chlorinated organic compounds, polychlorinated dibenzo-dioxins (PCDDs) and polychlorinated dibenzo-furans (PCDFs), which differ in the number and position of chlorine atoms on the basic underlying chemical structure. They are formed unintentionally and released as byproducts of human activities such as fuel combustion, waste incineration, chlorine bleaching of pulp and paper, pesticide manufacturing, as well as by natural processes such as forest fires and volcanoes (U.S. Environmental Protection Agency, 2000). Dioxins are widely distributed in the environment at low concentrations, and combustion processes are believed to be the major cause of this (Czuczwa and Hites, 1984). Their persistence in the environment and highly lipophilic property render dioxins bioaccumulating and biomagnifying through food webs into different trophic levels of organisms, including humans. The toxicity of each member of the dioxin family varies considerably and is usually expressed by a toxic equivalency factor (TEF) relative to the most toxic of the congeners, 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). The U.S. Environmental Protection Agency (2000) has characterized 2,3,7,8-TCDD as a “human carcinogen” and the mixture of dioxins to which people are usually exposed as “likely human carcinogens”.

It is difficult to estimate the extent of dioxin pollution across China because they are unintentionally produced in many industrial and combustion-related processes. Regional monitoring data indicate the widespread occurrence of dioxins is already a serious environment issue. For instances, sediments from Ya-er Lake in Hubei Province, which received wastewater discharged from a factory manufacturing chlorinated organic chemicals, contained 0.16–797 ng I-TEQ/g (dry wt.) of PCDD/Fs (Wu et al., 1997). Agricultural soils in the vicinity of a municipal solid waste (MSW) incinerator in Hangzhou, Zhejiang province contained 0.60–6.38 ng I-TEQ/kg of PCDD/Fs, which resulted mainly from open burning of wastes, traffic and hot water boilers, but with limited contribution from the incinerator (Xu et al., 2009a). Surface soils around Beijing showed a mean background dioxin level of about 0.88 ng WHO-TEQ/kg, which is comparable to those of lightly polluted urban and industrial soils of other countries (Chen et al., 2003). The concentrations of PCDD/Fs in the sewage sludge from 6 wastewater treatment plants in Beijing ranged from 3.47–88.24 ng I-TEQ/kg (dry wt.), although their sources were unknown (Dai et al., 2007). Screening of human breast milk

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doi:10.1016/j.envpol.2010.06.014

samples using the 7-ethoxyresorufin O-deethylase (EROD)-TEQ assay showed that the mean EROD-TEQ values ranged from 58.1 to 96.5 pg/g of milk fat for Hong Kong residents aged 21–36 years, while the levels of dioxin-like compounds in a comparable group from Guangzhou were much higher (98.8–202.1 pg/g of milk fat) (Lai et al., 2004). Zheng et al. (2008) presented a comprehensive review of PCDD/F pollution in China and compared the levels found in different environmental media and in food with those reported in other countries. Due to the widespread pollution and their extreme toxicity, there is an urgent need to curb the release of dioxins to protect the environment and human health in China.

As one of the countries with large amounts of dioxin releases (approximately 10 kg I-TEQ/year), the control of dioxins is the biggest challenge for China to reduce pollution from persistent organic pollutants (POPs) (People's Republic of China, 2007). A preliminary inventory reveals that ferrous and non-ferrous metal production (45.6%), heat and power generation (18.5%), medical waste incineration (11.5%) and uncontrolled combustion processes (9.9%) contribute to the vast majority of dioxins released in China (Table S1, Supplementary Material). As part of the national implementation plan for the Stockholm Convention, which calls for global elimination or restriction of the production and use of POPs, China aims to adopt the best available techniques and best environment practices (BAT/BEP) to control the increasing trend of dioxin releases by 2015 (People's Republic of China, 2007).

Unlike most of the industrialized countries where MSW incineration is the major source of dioxins (U.S. Environmental Protection Agency, 2000), the contribution from waste incineration (338 g I-TEQ/year) to the total amount of dioxins released is relatively small (3.3%) (People's Republic of China, 2007). Nonetheless, MSW, hazardous and medical waste incineration should be considered high priority sources in dioxin control owing to the rapidly increasing reliance on incineration as an important way to dispose waste in the near future (Zhu et al., 2008). In the present work, we limit our scope to dioxin emissions from MSW incineration, although some of the discussions are also applicable to the incineration of hazardous and medical wastes.

2. Development of MSW incineration in China

With China's rapid economic development, the country is undergoing unprecedented urbanization, and disposal of the increasing volume of MSW generated presents a major challenge for the municipalities (Cheng and Hu, 2010a,b, 2009; Cheng et al., 2007). More than 150 million tonnes of MSW is produced each year, and MSW generation is increasing at an annual rate of 8–10% (Tables S2–S3, Supplementary Material). Incineration transforms heterogeneous wastes into more homogeneous residues (flue gas, fly ash and bottom ash) with the primary benefit of substantial reduction of the waste's weight and volume (up to 75% and 90%, respectively). Energy from the discarded MSW can be recovered during incineration through steam generation, which is subsequently used for power generation and/or heating (waste-to-energy, WTE). Besides reducing the need for landfill space and generating energy, incineration also reduces the transport of MSW to distant landfills and the associated fuel consumption and greenhouse gas emissions (Kaplan et al., 2009; Weitz et al., 2002).

A growing number of cities, particularly those in the economically more developed coastal region, are switching to incineration as the preferred option in MSW management. The percentage of MSW treated by incineration increased from 2.9% to 12.9% from 2001 to 2005 (Nie, 2008). With the exception of few small-scale (100–200 t/d) incinerators, all MSW incineration facilities are operated as WTE plants in China. A total of 63 MSW incineration facilities with a combined capacity of 800 MW were in operation in 2006, treating approximately 40,000 tonnes of MSW (Table S4, Supplementary Material). During the 11th five-year plan period (2006–2010), another 82 facilities are being built and planed, adding a total incineration capacity of 66,600 tonnes/day (Table S5, Supplementary Material). It is expected that incineration will play an increasingly important role in MSW management in China in the coming decade (Cheng and Hu, 2009, 2010b).

3. Formation and destruction of dioxins in MSW incineration

The dioxins emitted from MSW incinerators result from a balance of destruction and formation processes. Fig. 1 shows the major pathways for PCDD/F formation in the flue gas and fly ash. Overall, formation of PCDD/Fs depends on the evolution of precursors within combustion gases, the interactions with reactive fly ashes, and the presence of oxygen, transition metal catalysts, and gaseous chlorine (Fiedler, 1998; Weber, 2007; Altarawneh et al., 2009). Temperature of the combustion gases is the single most important factor in dioxin formation, with maximum formation occurring at around 350 °C and minimum formation outside the range of 200–450 °C. Dioxins can be totally destructed in the combustion environment when the following criteria are met: (i) homogenous high temperature of >850 °C; (ii) excess of oxygen (>6%), and (iii) sufficient residence time (>2 s). Their formation in thermal processes can also be inhibited by various chemicals, such as CaO, sulfur and nitrogen compounds (Altarawneh et al., 2009).

Modern MSW incinerators are well equipped for dioxin control. Fig. 2 illustrates the locations for the formation, destruction, and removal of dioxins in a typical MSW incineration facility. In general, maximum destruction of dioxins during incineration can be achieved by a combination of high combustion temperature, adequate combustion time, and turbulence to distribute heat evenly throughout the combustion chamber, while dioxin formation in the post-combustion zone can be prevented by quickly cooling the flue gas exiting the combustion chamber (to temperatures below 200 °C), and minimizing the presence of the catalytic metals. In addition, PCDD/Fs can be further removed by the air pollution control devices (APCDs) installed for flue gas cleaning.

4. Status of dioxin releases from MSW incineration and recommendations for management policies and practices

Emission rates of dioxins from MSW incinerators in China are generally higher compared to those in the developed countries (<0.5 μg I-TEQ/tonne). Most of the large incinerators in China are directly imported or based on foreign technologies, while the domestically developed incinerators are limited to 100–500 t/d treatment capacities (Cheng and Hu, 2010b). The emission factors of PCDD/F compounds to the atmosphere from the domestic incinerators varied largely, and the average emission factor was approximately 1.73 μg I-TEQ/tonne (Ni et al., 2009). A study in 2001 found that atmospheric emissions of dioxins from half of the small incinerators exceeded the national standard of 1.0 ng I-TEQ/Nm^3 (Tian and Ouyang, 2003). More recent studies reported that concentrations of dioxins emitted from MSW incinerators were generally in compliance with the Chinese standard, and could even meet the European one (0.1 ng I-TEQ/Nm^3) for the large-scale ones adopting the best available air pollution control technologies (Nie, 2008; Ni et al., 2009; Xu et al., 2009b).

Development of strategies and action plans for controlling the release of dioxins from MSW incineration is an important task. Table 1 summarizes the technologies and MSW management