Waste Management xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Catalytic destruction vs. adsorption in controlling dioxin emission

Wei Ting Hsu, Pao Chen Hung, Moo Been Chang *

Graduate Institute of Environmental Engineering, National Central University, 300 Jhong-da Road, Jhongli, Taoyuan 32001, Taiwan, Republic of China

ARTICLE INFO

Article history:
Received 6 March 2015
Revised 11 July 2015
Accepted 1 September 2015
Available online xxxx

Keywords:
Catalytic filter
PCDD/Fs
Hazardous waste incinerator
Industrial waste incinerator
Activated carbon injection

ABSTRACT

This study investigates the removal efficiencies of PCDD/Fs achieved with a catalytic filter (CF) and with activated carbon injection followed by bag filter (ACI + BF) as applied in an industrial waste incinerator (IWI) and a hazardous waste incinerator (HWI), respectively. Catalytic filtration has been successfully applied to remove PCDD/Fs from gas streams. Comparing the CF to the ACI + BF system, it appears that the PCDD/F removal efficiency achieved with a CF is higher than that of an ACI + BF system. The PCDD/F emissions from both incinerators are well controlled to meet the regulatory limit of 0.1 ng I-TEQ/Nm^3. Additionally, the PCDD/F concentration in BF ash is higher than the regulation limit of Taiwan (1.0 ng I-TEQ/g). In contrast, the PCDD/F concentration in CF ash is only 0.274 ng I-TEQ/g. The difference is attributed to the fact that the ACI + BF system just transfers PCDD/Fs from gas phase to solid phase and further increases the PCDD/F concentration in fly ash, while CF technology effectively destroys the gas-phase PCDD/Fs. Therefore, the disposal of the fly ash discharged from CF would be less expensive compared with the fly ash discharged from the ACI + BF system. In this study, the PCDD/F emission factors of both incinerators are also established.

1. Introduction

Emissions of polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) from stationary sources have been extensively studied because of their significant toxicological importance and associated adverse health effects. PCDD/Fs are listed as the persistent organic pollutants (POPs) by the Stockholm Convention, an international environmental treaty aiming to eliminate or restrict the production and use of POPs. A total of seventeen 2,3,7,8-substituted PCDD/Fs continue to be of ongoing concern, regarding of their high toxic equivalency factors (TEFs), bioaccumulation, carcinogenicity and mutagenic potential (Behnisch et al., 2001). The sources of PCDD/Fs are generally divided into four major categories including incineration, combustion, industrial and reservoir sources (Kulkarni et al., 2008). On the global scale, incineration is a major contributor to PCDD/F emissions (Wielgosiński, 2010). Previous studies indicate that PCDD/Fs emitted from hazardous waste incinerators (HWI) ranged from 0.32 to 16.4 ng I-TEQ/Nm^3, which are significantly higher than that of industrial waste incinerators (IWI) with mean concentration of 0.15 ng I-TEQ/Nm^3 in the flue gas (Lin et al., 2006; Yan et al., 2011). Generally, hazardous wastes are classified into explosive, oxidizing, highly flammable, infectious, poisonous, harmful, toxic, carcinogenic and corrosive wastes (UNEP, 2014). These wastes are possibly releasing hazardous substances into water, air and soil. A practice of separating hazardous waste for incineration has also been started in Taiwan since the mid-1990s. Hazardous or toxic wastes including polychlorinated biphenyls (PCBs) can be incinerated and treated in high temperature (Van Caneghem et al., 2014).

Taiwan EPA estimates the quantities of wastes treated by industrial waste incinerators (IWI) and hazardous waste incinerators (HWI) were approximately 820,500 and 89,700 tons, respectively, in 2006 (Lin et al., 2007). However, specific information on PCDD/F emissions from individual hazardous waste incinerator is scarce, and the effect of IWI/HWI on the ambient PCDD/Fs has not yet been fully investigated in Taiwan.

Two technologies including adsorption with activated carbon (AC) and catalytic destruction are commonly applied to control PCDD/F emissions from waste incinerators. Our previous study demonstrated that partitioning of PCDD/Fs between the vapor and solid phases changes significantly as the flue gas passes

Abbreviations: CF, catalytic filter; PCDD/Fs, polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans; HWI, hazardous waste incinerator; IWI, industrial waste incinerator; PCBs, polychlorinated biphenyls; ACI, activated carbon injection; APCDs, air pollution control devices; POPs, persistent organic pollutants; TEQ, toxic equivalency; BF, bag filter; PM, particulate matter; PAC, powder activated carbon; GSA, gas suspension absorber; ESP, electrostatic precipitator; SDS, semidry scrubber; WS, wet scrubber; SCR, selective catalytic reduction; RE, removal efficiency; EF, emission factor.

* Corresponding author.
E-mail address: mbchang@ncuen.ncu.edu.tw (M.B. Chang).

http://dx.doi.org/10.1016/j.wasman.2015.09.002
0956-053X/© 2015 Published by Elsevier Ltd.

through different APCDs (Chang et al., 2004; Chi and Chang, 2005). Congener's vapor pressure, operating temperature, particle concentration and removal mechanism of APCDs are key parameters controlling the phase distribution. Solid-phase PCDD/Fs can be removed by particulate matter controlling system such as bag filter (BF). In contrast, gas-phase PCDD/Fs in the flue gas would pass through the BF. Gas-phase PCDD/Fs must be removed by adsorption on carbon-based adsorbents or catalytic destruction. Consequently, this study investigates the PCDD/F removal efficiencies achieved with a catalytic filter (CF) and an "activated carbon injection + bag filter" (ACI + BF) system applied in the IWI and the HWI, respectively. Finally, the PCDD/F concentrations in the flue gas before and after APCD and fly ash generated from APCDs are also measured.

In 2000, W.L. Gore and associates proposed a system for PCDD/Fs destruction through the use of catalytic filters (REMEDIA™). These filters consist of membranes of expanded PTFE containing the catalyst (Gore (USA), http://www.gore.com/remedia). Xu et al. (2000) indicated that the catalytic filter can simultaneously remove solid-phase PCDD/Fs from the flue gas and destroy gas-phase PCDD/Fs at a temperature range of 160–260°C. Gas-phase PCDD/Fs are converted mainly into CO_2, H_2O, and HCl. The dual-layer design with membrane and catalytic felt allows effective removal of particulate matter (PM) and destruction of gaseous PCDD/Fs (Syc et al., 2006). Nowadays, this catalytic filter has been successfully applied to remove PCDD/Fs from gas streams of various thermal processes in Europe, USA, Japan and Singapore. Previous research shows that more than 99.5% of the gaseous PCDD/Fs entering the catalytic filter are destroyed, and the PCDD/F emissions are well controlled to below the regulatory limit of 0.1 ng I-TEQ/Nm^3 (Fritsky et al., 2001; Pařízek et al., 2008). In our previous study, the removal efficiencies of chlorobenzene/chlorophenol (CBz/CPh) by CF and ACI + BF system were also evaluated (Hung et al., 2014a).

Activated carbon is a porous material which has large adsorption surface area and can achieve high PCDD/Fs adsorption efficiency (Karademir et al., 2004). Several factors may affect the adsorbing capacity of AC, such as the characteristics of AC, the nature and concentrations of adsorbates, and the operating conditions, including gas temperature and humidity. Previous study indicates that ACI is effective in removing PCDD/Fs from MWIs to meet the emission standard (0.1 ng I-TEQ/Nm^3) (Chang and Lin, 2001). PCDD/Fs can be efficiently adsorbed by powdered activated carbon (PAC) injected into the flue gas, and then the PCDD/F-containing PAC and the particulate matter are simultaneously collected by bag filtration (Lu et al., 2013). However, ACI just transfers PCDD/Fs from the gas phase to solid residues, and high cost is incurred to dispose of the BF ash generated (Everaert et al., 2003). In contrast, the PCDD/F content in filter dust can be effectively reduced by applying catalytic filtration (Hung et al., 2014b).

In this study, PCDD/F removal efficiencies achieved with two different air pollution control devices (APCDs), at an IWI and a HWI, respectively, in Taiwan are evaluated via intensive stack sampling and analysis. Emission of toxic substances from waste incinerators is highly dependent on the plant configuration and the characteristics of feeding materials.

The PCDD/F emission factors have been established to estimate the total emissions from the stacks, to build up the emission inventory and to enact the control strategy. However, the PCDD/F emission factors depended on the variation in incineration processes, the difference in feeding materials, and the advancement of air pollution control devices with time (Lin et al., 2006). In order to better evaluate the PCDD/Fs emissions for environmental management, updating the PCDD/F emission factors is essential.

Table 1
The operating conditions and characteristics of the IWI and HWI investigated.

	IWI	HWI
Facility type	Fluidized bed	Rotary kiln
APCDs	CF	GSA and ACI + BF
Stack temperature (°C)	172	150
Capacity (ton/day)	144	73.4
Injection rate of activated carbon (kg/h)	N.A[a]	3.6
Flow rate of the flue gas (Nm^3/h)	33,100	23,200
Average O_2 content of the flue gas (%)	11.4	10.2
Average CO_2 content of the flue gas (%)	7.0	7.8
Average $H_2O_{(g)}$ content of the flue gas (%)	25.7	19.6
PM concentration (mg/Nm^3)	CF inlet: 2,204	BF inlet: 5,960
	CF outlet: 2.0	BF outlet: 3.4
PM removal efficiency (%)	>99.9	>99.9

[a] Not available.

2. Investigation and sample analysis

The IWI and HWI selected for this investigation are both located in northern Taiwan. The operating conditions of the IWI and HWI investigated in this study are presented in Table 1. In this investigation, the O_2, CO_2 and H_2O contents of the flue gas are measured by a direct reading analyzer (TESTO 350).

2.1. Feeding material in IWI/HWI

The feed materials to the IWI are mainly composed of waste plastics and sludge. Waste plastics including tape and ribbon are collected from facilities of waste paper recycling. Sludge is

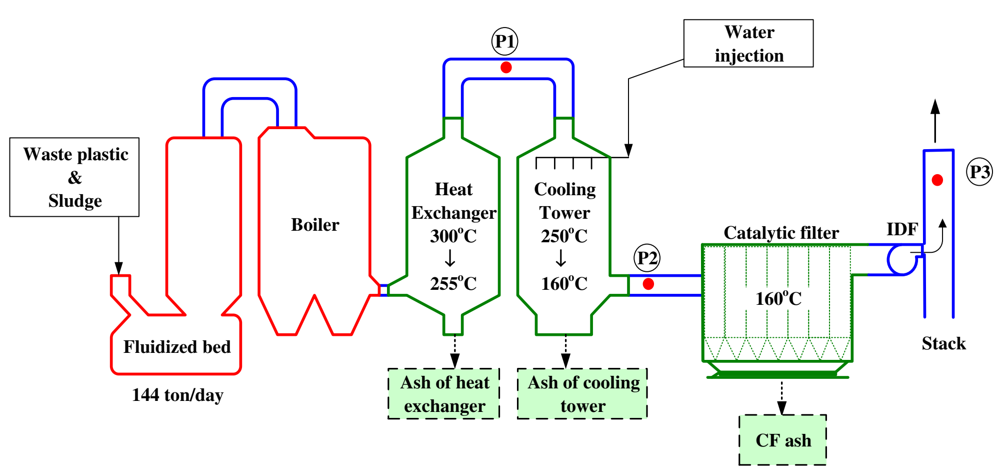

Fig. 1. Schematics and sampling locations of the IWI investigated.

Please cite this article in press as: Hsu, W.T., et al. Catalytic destruction vs. adsorption in controlling dioxin emission. Waste Management (2015), http://dx.doi.org/10.1016/j.wasman.2015.09.002