

# The prediction of PCDD/DF levels in wet scrubbers associated with waste incinerators

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## Abstract

Wet scrubber is one of the most conventional types of air pollutant control devices (APCDs), which is specially designed to treat dust and acidic gases in the flue gas simultaneously. In spite of its outstanding ability to control them, however, wet scrubbers have been considered as potential contaminant sources that may increase PCDD/DF concentrations in the flue gas. In this study, we investigated the change of PCDD/DF concentrations at the inlets and outlets of seven wet scrubbers, and compared them with other published data. With a multi-regression analysis of dust concentrations and temperature at the inlets and outlets of given wet scrubbers, we developed an empirical model to understand factors dominating the change of PCDD/DF concentrations. As a result, we confirmed that the changes of PCDD/DF concentrations in wet scrubbers are closely related to their concentrations at the inlets, which would usually be determined by the type of APCDs installed upstream of the wet scrubber.

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## 1. Introduction

To solve an increasing problem in finding new landfill sites, largely as a result of the ‘not in my back yard’ (NIMBY) syndrome, incineration has been widely adopted as one of the preferred alternatives for waste treatment in many countries. However, it has also led to the serious concern for the secondary contamination by the unexpected toxic pollutants emitted from waste incinerators, having become one of the hotly debated environmental issues for many years. One outcome has been a re-evaluation of the efficiency of air pollutant control devices (APCDs) for hazardous air pollutants, such as polychlorinated dibenzo-*p*-

dioxins, polychlorinated dibenzofurans (PCDD/DF), and polychlorinated biphenyls. In particular, attention has been directed to the role of the older style of APCDs, and their established weaknesses have been assessed.

Wet scrubbers are among the more conventional types of APCDs that are specially designed to treat acidic gases and particulate matter simultaneously. They have been subject to more or less continuous development, with various combinations tried in an effort to improve their efficiency (Ebert and Butter, 1996; Lehner et al., 2001; Andersson et al., 2003). Because previous research on wet scrubbers has tended to focus on dust and acidic gases (e.g., Onnen, 1972; Cheremisinoff and Young, 1977), however, the control of PCDD/DF by wet scrubbers has come to the attention of researchers only recently. Wevers et al. (1992) found that wet scrubbers could efficiently remove HCl, HF and

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SO<sub>2</sub>, and their removal efficiencies were 99.5%, 97% and 37% respectively. In addition, they observed that about 70% of PCDD/DF ( $21.4 \pm 21.8$  ng TEQ N m<sup>-3</sup> at the inlet and  $6.3 \pm 5.7$  ng TEQ N m<sup>-3</sup> at the outlet), or about the same quantity as dust, could be removed in this scrubbing procedure. Lehner et al. (2001) confirmed that the advanced compact wet scrubber was highly effective in separating PCDD/DF, as well as fine dust particles and inorganic gaseous pollutants (HCl, HF, SO<sub>2</sub>). They supposed that the decrease of PCDD/DF might result from their significant adsorption into plastic packing materials.

Despite these positive results, other studies have indicated that the gas scrubbing procedure in wet scrubber has the potential to increase the level of PCDD/DF. Sierhuis et al. (1996) reported that PCDD/DF levels in flue gases increased by 1.8–3.0 times as a result of scrubbing with no activated carbon. Bassetti et al. (1999) observed that the wet scrubber, installed downstream of the electrostatic precipitator, did not effectively remove PCDD/DF, especially those in the gaseous phase. They presented that the removal efficiency of PCDD/DF was the least when the dust concentrations at the inlets had been lower than 1 mg/N m<sup>3</sup>, which might result from the inherent weakness of wet scrubbers to cope with smaller particles. Gass et al. (2000) found that toxicity equivalents (TEQ) of PCDD/DF at the outlet were 7.8–26.3 times higher than those at the inlets of wet scrubbers, and Kim et al. (2001) observed that TEQ of PCDD/DF in flue gases increased up to 60-fold in several wet scrubbers. Of particular interest in their studies was what all PCDD/DF increases had occurred in the wet scrubbers, installed downstream of high efficient APCDs. From the concentration change of PCDD/DF in a wet scrubber, Giugliano et al. (2002) emphasized that the significant enhancement of PCDD/DF would be originated from their desorption from the wall materials, and Takaoka et al. (2003) observed TEQ increases of 1.5–16.6 times in two wet scrubbers. With a long-term monitoring of PCDD/DF, Löthgren and Bavel (2005) found that the elevated PCDD/DF levels in the wet scrubbers during or after start-up periods had slowly decreased, which might provide valuable evidence on the thermal adsorption/desorption of PCDD/DF on the packing materials. In addition, they proposed a PCDD/DF desorption model, which was in agreement with the change of homologous pattern. On the other hand, a similar trend is also easily observable in the case of total congeners (Kreisz et al., 1996; Hunsinger et al., 1998; Gass and Neugebauer, 1999; Giugliano et al., 2002).

In this study, it has been investigated the changes of PCDD/DF in the wet scrubbers, being associated with their concentrations at the inlets, as well as the changes of temperature and dust, and, based on their relationships, an empirical equation with multi-regression analysis has been proposed to quantitatively predict the extent of any increases in PCDD/DF concentrations in wet scrubbers, and to understand factors affecting the PCDD/DF memory effect.

## 2. Materials and methods

To ascertain the extent and characteristics of the changes of PCDD/DF concentrations in the wet scrubbers, PCDD/DF as well as temperature and dust were measured at both the inlets and outlets of wet scrubbers in seven municipal solid waste incinerators. An outline of the selected seven waste incinerators is shown in Table 1. Four incinerators were equipped with both cyclones (CY) and wet scrubbers as their APCDs, whereas electrostatic precipitators (EP) and fabric filters (FF) were also employed upstream of the wet scrubbers in the three other incinerators. The scrubbing solutions were circulated and replenished continuously, and no activated carbon was used in all facilities.

For sampling and analyzing of PCDD/DF, the Korean standard testing method for dioxins and furans (NIER, 2004) was used. Both of PCDD/DF and dust were sampled twice at the inlets and outlets of the scrubbers respectively, and the temperatures were checked every 5 min at the same points during the PCDD/DF sampling. Each sampling for PCDD/DF was performed for 120–240 min, to obtain a sufficient gas volume (about 1–3 N m<sup>3</sup>). The samples for PCDD/DF were extracted with toluene in a Soxhlet extractor, and with dichloromethane in a liquid–liquid extraction procedure. After extraction, each sample was subjected to a series of cleanup processes, such as sulfuric acid treatment, multi silica gel column and alumina column. The concentrations of PCDD/DF in final samples were determined using a high resolution gas chromatograph (HP 6890N, Hewlett-Packard)/high resolution mass spectrometer (Autospec Ultima NT, Micromass) with SP-2331. TEQ values (as 2,3,7,8-TCDD) were recalculated with international toxicity equivalency factors.

## 3. Results and discussion

### 3.1. Prediction of the changes of PCDD/DF concentrations in wet scrubbers

Concentrations of PCDD/DF at inlets and outlets of wet scrubbers and their variation ratio (=outlet TEQ/inlet TEQ) are shown in Table 2. These concentrations at the inlets and outlets ranged from 0.23 to 37.37 and from 0.76 to 5.95 ng TEQ N m<sup>-3</sup>, respectively. With the exception of scrubbers F and G, the average removal efficiency of PCDD/DF was 71%. However, the PCDD/DF concentration was stable in wet scrubber F, and increased about nine-fold in wet scrubber G.

In Fig. 1, the concentrations of PCDD/DF are plotted against their variation ratios for the seven scrubbers. It is assumed that the changes of PCDD/DF concentrations in wet scrubbers would be strongly affected by their concentrations at the inlets, which in turn would be largely determined by the efficiency of APCD that existed upstream in the processing line. In other words, if the gases were not treated adequately before the wet scrubber, these

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