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Research article

Emission of greenhouse gases from waste incineration in Korea

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ABSTRACT

Greenhouse gas (GHG) emission factors previously reported from various waste incineration plants have shown significant variations according to country-specific, plant-specific, and operational conditions. The purpose of this study is to estimate GHG emissions and emission factors at nine incineration facilities in Korea by measuring the GHG concentrations in the flue gas samples. The selected incineration plants had different operation systems (i.e., stoker, fluidized bed, moving grate, rotary kiln, and kiln & stoker), and different nitrogen oxide (NO_x) removal systems (i.e., selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR)) to treat municipal solid waste (MSW), commercial solid waste (CSW), and specified waste (SW). The total mean emission factors for A and B facilities for MSW incineration were found to be 134 ± 17 kg CO_2 ton^{-1}, 88 ± 36 g CH_4 ton^{-1}, and 69 ± 16 g N_2O ton^{-1}, while those for CSW incineration were 22.56 g CH_4 ton^{-1} and 259.76 g N_2O ton^{-1}, and for SW incineration emission factors were 2959 kg CO_2 ton^{-1}, 43.44 g CH_4 ton^{-1} and 401.21 g N_2O ton^{-1}, respectively. Total emissions calculated using annual incineration for MSW were 3587 ton CO_2-eq yr^{-1} for A facility and 11,082 ton CO_2-eq yr^{-1} for B facility, while those of IPCC default values were 13,167 ton CO_2-eq yr^{-1} for A facility and 32,916 ton CO_2-eq yr^{-1}, indicating that the emissions of IPCC default values were estimated higher than those of the plant-specific emission factors. The emission of CSW for C facility was 1403 ton CO_2-eq yr^{-1}, while those of SW for D to I facilities was 28,830 ton CO_2-eq yr^{-1}. The sensitivity analysis using a Monte Carlo simulation for GHG emission factors in MSW showed that the GHG concentrations have a greater impact than the incineration amount and flow rate of flue gas. For MSW incineration plants using the same stoker type in operation, the estimated emissions and emission factors of CH_4 showed the opposite trend with those of NO_2 when the NO_x removal system was used, whereas there was no difference in CO_2 emissions.

1. Introduction

A large amount of waste is being generated due to economic development, population growth, and increased consumption. Waste incineration as a waste disposal method is increasing in popularity worldwide due to the lack of land and the potential for soil and water pollution associated with landfilling, as well as the added benefit of the potential for energy recovery from incineration (Harris et al., 2015).

Greenhouse gases (GHGs) emitted from waste incineration processes include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), with emissions of CO_2 being more significant than those of CH_4 and N_2O (IPCC, 2006a,b). The production of household and industrial waste in Korea totaled 48,000 and 96,000 tons per day in 1995, respectively. By 2012, the production of household and industrial waste had changed to 49,000 and 146,000 tons per day, respectively, that is, an increase of approximately 1.5 times for industrial waste (GGIRCK, 2014). In addition, emissions from the waste sector were 14.8 million tons of CO_2 equivalent (CO_2 eq) in 2012, accounting for 2.2% of the total emissions in Korea. This was a 49.4% increase compared to the 1990 level and a 1.6% increase from the 2011 level (GGIRCK, 2014). In 2014, total waste generation in Korea was approximately 388,000 tons per day and the recycling rate was 84.8%, which represented a 0.9% increase from the 2013 level (landfill: 9.1%, incineration: 5.8%, other: 0.3%) (MOE, 2015a,b,c). In contrast, in Europe, approximately 22% of waste is

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currently incinerated. The amount of incineration is increasing due to the EU Landfill Directive (Harris et al., 2015), and GHG emissions from the waste sector emission now account for 152 million tons CO_2 eq, which represents a 37.7% decrease from the 1990 level (EEA, 2015).

Previous studies have reported various values for GHG emissions and emission factors that are specific to certain countries, waste type, and waste management practices. Astrup et al. (2009) measured direct emission from a combustion plant as well as indirect upstream contribution. The content of fossil carbon in the input waste was found to be approximately 40% of the direct fossil carbon-related emissions. It was reported that the separate collection of municipal waste as a management practice affected GHG emissions (Calabrò, 2009), with fossil carbon emission factors ranging from 27 to 40 kg CO_2/GJ for residual household waste incineration (Larsen and Astrup, 2011). Also, a life cycle assessment (LCA) of a selective non-catalytic reduction (SNCR) NO_x-cleaning system, operating with an ammonia slip (i.e., loss of ammonia) demonstrated an effect on GHG emissions (Møller et al., 2011). Direct and indirect emissions of CO_2-eq and NOx were examined for a district heating system using LCA principles and were compared to a hypothetical scenario where the most likely alternative waste treatment and heat supply technologies were used (Brattebø and Reenaas, 2012). Annual mean fossil carbon emissions from five Swiss incinerators were calculated using the radiocarbon (^{14}C) method, and were found to be between 43.4 $\pm$ 3.9 and 54.5 $\pm$ 3.1%, with the variations explained by the waste composition of the respective plants (Mohn et al., 2012). Recently, the emissions and emission factors of N_2O and CH_4 gases at five waste incineration facilities burning a mixture of household and industrial waste with grate firing in Swiss were reported (Harris et al., 2015). For the removal of NO_x, two of the plants used selective non-catalytic reduction (SNCR), while three plants used selective catalytic reduction (SCR). They found that N_2O emissions at incineration plants using SCR were ten times lower than at facilities using NSCR (Harris et al., 2015).

In Korea, CO_2 emissions from different waste incineration type, namely, municipal, industrial, construction, and hazardous waste between 1998 and 2005 were determined by applying the annual mean carbon contents reported in the national waste survey (Jang et al., 2008). There were several reported studies which reported GHG emission using measured data from incineration plants (Kan et al., 2008; Kim et al., 2010; Park et al., 2011). Emissions of CO_2 and N_2O were examined at six incineration plants treating different waste streams, that is, municipal, industrial (with sludge), construction, and specified waste (with sludge) by analyzing the flue gas (Kan et al., 2008; Kim et al., 2010). Park et al. (2011) also examined N_2O emissions and emission factors from three municipal solid waste (MSW) incinerators in Korea treating with either a stoker type or both the stoker and rotary kiln types for NO_x removal. The emission factors from the three different plants were calculated as 71, 75, and 153 g-N_2O/ton-waste, respectively. All these studies have suggested that GHG emissions and emission factors vary according to the type of waste incineration, plant operation (e.g., NO_x removal types), and local waste management practices, thus more comprehensive data is required to calculate the national GHG emission factors from waste incineration facilities in Korea using the 'bottom-up' measurement of plant-specific GHGs. However, the data obtained from their studies are not yet sufficient to produce GHG emission factors in national level in Korea.

In this study, we estimated the emission factors by measuring GHG such as CO_2, CH_4, and N_2O from the flue gases at nine selected waste incineration plants which cover different operation systems (i.e., stoker, fluidized bed, moving grate, rotary kiln, and kiln & stoker), different nitrogen oxide (NO_x) removal systems (i.e., selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR)), and different waste types such as municipal solid waste (MSW), commercial solid waste (CSW), and specified waste (SW), respectively. The effects of the waste types, NO_x removal methods, and combustion temperatures in the incineration plants, on the GHG emission factors were examined in details. The results obtained in this study were used to comprehensively provide national GHG emission factors in each type of incineration facilities in Korea.

2. Materials and methods

2.1. Waste generation in Korea

In Korea, the waste classifies as municipal waste (e.g., solid and food waste from households, industrial processes, and commercial activities), treatment waste (e.g., sludge and residues from municipal, industrial, and human or livestock waste treatment facilities), construction waste, specified or designated waste (e.g., acids and alkalis, oil, organic solvents, synthetic polymers, fly ash sludge from industrial sites, which contains hazardous ingredients and needs safe management), and medical waste, respectively (MOE, 2008a,b; 2015a,b,c).

Between 2007 and 2014, the total amount of waste generated in Korea steadily increased by 27% (i.e., approximately 3.8 million tons in 2007 to 5.2 million tons in 2014), compared to population growth of 4%. Over the same period, the generation of treatment, construction, specified, and medical waste increased by 25, 7, 27, and 52%, respectively, while the generation of municipal waste slightly decreased by 1%. Furthermore, in this period, the total amount of wastes treated by landfill, incineration, and recycling increased by 15, 24 and 30%, respectively, indicating that recycling rates are increasing, and the use of "Waste to Energy" (WTE) plants is also increasing (MOE, 2008a,b; 2015a,b,c).

2.2. Characteristics of selected waste incineration plants

As shown in Table 1, the total number of MSW incineration facilities in Korea is 180 in 2007, with the waste treating capacity of A and B facility is 12,500 kg/hr and 8333 kg/hr, respectively. There were a total of 1016 CSW incineration facilities in workplace of the self-processing companies in 2007, and the capacity of the C facility was 5834 kg/hr (MOE, 2008a,b). In addition, the total number of facilities handling specified waste (SW) (waste oil, other organic solvents, waste acid, waste alkali, and waste synthetic resin, etc.) amounted to approximately 180 in 2007 (MOE, 2008a,b). Therefore, it is considered that the selected facilities for sampling in this study can represent various incineration facilities in Korea.

Table 2 shows the characteristic details of nine selected waste incineration plants in Korea, in terms of their operation types, NO_x removal technologies, and other information related to the estimation of GHG emissions. Flue gas samples were collected from these plants between August 2005 and August 2007. Plants A and B were operated by local authorities to incinerate MSW and were continuous stoker types. For NO_x removal, facility A had an SCR system, while facility B had an SNCR system. Plant C was operated privately to treat solid waste with continuous fluidized bed combustion technology and an SCR system to treat the off-gas. Plants D to I were operated continuously with SNCR systems, to treat specified or designated waste. A kiln & stoker or a stoker-only was used in these plants except that the plant F additionally had a moving grate and plant G had a rotary kiln.