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Research article

Characterization of odorous gases at landfill site and in surrounding areas

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ABSTRACT

Concentration levels and seasonal variation of odorous gases at landfill site and in surrounding areas within the city of Incheon, South Korea were investigated. Sampling was conducted at 11 points (5 at landfill site and 6 in surrounding areas). The highest concentrations of odorous gases (complex odor, ammonia, acetaldehyde, and VOCs) at landfill site were found in summer, probably due to fast decomposition of waste in high temperature related with more release of ammonia. In addition, specific weather condition of dominant wind direction, humidity and higher atmospheric pressure with no or lower wind speed caused positive effect of higher aldehyde compounds and VOCs concentration. Similar to other studies, sludge-related sampling site S-2, where a couple of odor generating facilities including sludge mixing and drying treatment process are located, showed the highest concentration levels of odorous gases compared to other sites. Odor generation frequency was in the order of acetaldehyde (68.8%) > ammonia (39.4%) > propionaldehyde (21.9%), which means the main substances generating the unpleasant odor at landfill site was recognized as aldehydes and ammonia due to combined effect of sludge-related facilities and meteorological conditions. Offensive odor was not a big pollution issue in most surrounding areas which are located within a circle of 5 km radius of the landfill except high odor generation frequency of acetaldehyde and propionaldehyde. Relative percentage differences (RPD) of odorous gases between day and night times at landfill site were below 10%, which indicates that the concentration differences in day and night were not severe. The relationship between concentrations of complex odor and designated offensive odor substances was analyzed statistically. At landfill site, the analysis shows that the correlation coefficient between the concentration of complex odor and ammonia was quite high (0.833), but it was much lower (0.129) in the surrounding areas due to considerably lower concentrations of these substances.

1. Introduction

Landfills are the final depositories of most industrial, construction, and municipal wastes, and are also potential sources of offensive odors causing annoyance in urban areas (Shon et al., 2005; Dincer et al., 2006; Saral et al., 2009). Odors from landfill sites originate from the atmospheric release of chemical compounds that are formed during the biological and chemical processes that occur during waste decomposition (El Fadel et al., 1997). The annoying odors released from landfills may degrade quality of life and create potential health hazards (Saral et al., 2009; Paoli et al., 2012) for those in surrounding communities. As a result, odor problems have become a continuous environmental concern for urban communities, particularly those located closest to landfills (Sironi et al., 2005; Dincer et al., 2006; Ying et al., 2012). Landfill gases are generated by anaerobic digestion of biodegradable wastes and mainly comprise methane (~50–60%), carbon dioxide (~40%), reduced sulfur compounds (RSCs), and some non-methane volatile organic compounds (NMVOCs) (Zou et al., 2003; Shon et al., 2005; Wang et al., 2006; Saral et al., 2009; Tagaris et al., 2012). The odor problem with biogas is generated from trace chemicals species such as hydrogen sulfide, esters, alkylbenzenes, ammonia, mercaptans, and other hydrocarbons with concentrations less than 1% (by

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volume) of the total landfill gas concentration (Saral et al., 2009; Tagaris et al., 2012; Gallego et al., 2014). Characterization and assessment of odorous VOCs from landfills has been carried out by several researchers, in which gas chromatography-mass spectrometry was used to analyze the composition of various odorous gases emitted from landfill sites (Davoli et al., 2003; Zou et al., 2003; Dincer et al., 2006). Monitoring and characterization of RSCs at different landfill sites have also been performed by many researchers (Muezzinoglu, 2003; Shon et al., 2005; Kim, 2006; Song et al., 2007; Ying et al., 2012; Yue et al., 2014). Kim et al. (2005) has conducted extensive studies on the emissions and characterization of malodorous sulfur compounds of landfill facilities. They have analyzed both the absolute and relative composition of landfill gases and explained their relationship with respect to five different RSCs (Kim et al., 2005; Kim, 2006).

Accurate and reproducible sampling and measurement of odor is always required for the appropriate control of odors from landfill sites, but the monitoring of the odor annoyance is not easy. Problems can arise at the sampling level as well as at the analysis level (Nicolas et al., 2006).

The sampling method employed is a key issue pertaining to odor characterization and measurement. The characterization and source identification of odor compounds were conducted from different areas within a landfill site. Nine sampling points were selected and 35 types of odorous substances were measured and quantified from these samples (Fang et al., 2012). Capelli et al. (2013) presented techniques and strategies for odor sampling for olfactometric analyses, and also gave an overview of the issues covered by current odor sampling legislation. The surface emission of landfill gas has also been measured and estimated using different samplers: radial diffusive samplers (Bruno et al., 2007) and an air flux chamber (Park and Shin, 2001). Paoli et al. (2012) performed a long-term study using lichens, as indicators of pollution, for monitoring the environmental effects of a solid waste landfill. Tagaris et al. (2012) presented an innovative approach to estimate odor dispersion around landfill sites, using odorless CH_4 as an “odor index”. Sironi et al. (2005) estimated an odor emission factor (OEF) for assessment and prediction of landfills odor impact and the estimated value had the potential to be used directly as an odor impact indicator at an existing landfill. Sarkar and Hobbs (2002) developed a relationship between odor intensity (defined as the perceived magnitude of a stimulus) and odor concentration (a measure of the detectability of the odor) using various psychophysical models and respective parameters for each of the models.

Seasonal variation of landfill methane emissions from solid waste disposal sites in Thailand was investigated (Wang et al., 2006) and the temporal variation of trace component emission from the working surface of a landfill in Beijing, China was surveyed (Duan et al., 2014). A questionnaire survey was conducted to get feedback from the people living within a circle of 2 km radius of the landfill, to determine the influence of odor on their society, health, and welfare, as well as their level of discomfort (Sakawi et al., 2011).

Lewkowska et al. (2016) elucidated characteristics of odor emissions for municipal wastewater treatment plant area including sludge processing, mechanical and biological treatment facilities. Due to biological technologies of wastewater treatment such as sludge-related process, odor-causing compounds could be produced (Lebrero et al., 2013; Talaiekhozani et al., 2016; Liu et al., 2016). Recent landfill site accepts mixed collected municipal solid waste and sewage sludge, and incorporates a sludge drying and disposal system which could be odorous sources of dominant compounds, for instant ammonia, aldehydes and VOCs (Fang et al., 2012). In addition, relationship between landfill gas emissions and weather conditions, such as atmospheric pressure, temperature, soil humidity, wind speed and rainfalls, were investigated to clarify seasonal and daily variations of odor concentrations (Lucernoni et al., 2016).

Studies on monitoring and characterization of landfill gases at various landfill sites in Korea located in Daegu, Donghae, Gunsan, and Jeju have been conducted (Park and Shin, 2001; Kim et al., 2005; Shon et al., 2005; Kim, 2006; Song et al., 2007), but few studies were performed at “Sudokwon” landfill which is the biggest one in Korea.

The objective of the present study was to investigate the comprehensive odor levels at Sudokwon landfill site and in the surrounding areas. The seasonal variation characteristics of odorous gases, including odor generation frequency, were evaluated. The odor concentrations during day and night were also analyzed and compared. In addition to this, the relationship between the concentrations of complex odor and designated offensive odor substances at a landfill, as well as in the surrounding areas, was analyzed statistically and discussed. Finally, significant sources of odorous compounds were identified based on analysis of monitoring data at landfill sites and surrounding areas.

2. Materials and methods

2.1. Site description

The Sudokwon landfill is the largest landfill site located on the west coastal area near Incheon, Korea. It was constructed in 1989, and has been in operation since 1992. It receives the municipal wastes from Seoul and its satellite cities in the greater metropolitan area. Detail basic information, such as characteristics of solid waste carried into the landfill have been provided in the electronic supplementary information Table S1. The total area and capacity of the landfill are 4.99 million m^2 and 140 million tons, respectively. Three big residential areas (Oryu, Kyungseo, and Cheongra) are located within 5 km northeast or southeast of the landfill site and odor becomes a problem from time to time in these areas. General information about the Sudokwon Landfill is given in Table 1. Landfill site (S-1-5) is located inside or the vicinity of the landfill boundary, while surrounding areas (S-6-11) are located 1.2–5.0 km away from the landfill boundary.

In the municipal solid waste (MSW)-related area, three sampling points (S-3, S-4 and S-5) were placed in the active landfill area and one sampling point (S-2) was placed in the vicinity of eco-complex as facility-related area to investigate the effects of emitted odorous compounds from a leachate treatment plant, two sludge recovery facilities, a refuge derived fuel (RDF) plant and a waste solidification facility. There was one sampling point (S-1) in the closed landfill area to monitor the background concentration level of landfill site. In addition, six sampling points (S-6, S-7, S-8, S-9, S-10 and S-11) were placed near landfill site as surrounding area to compare the effect of odor emission based on distance from landfill sampling points and weather conditions.

The detailed description of the sampling points is given in Table 2 and the location and sampling points of the landfill and surrounding areas are shown in Fig. 1.

2.2. Field sampling

2.2.1. Sampling status

The field sampling was conducted for 2 days (winter), 4 days (spring), 4.5 days (summer), and 5.5 days (autumn) in 2014. Samples were collected twice a day (1st sampling: 14:00–16:00, 2nd sampling: 20:00–22:00). Sampling times were determined by considering the land filling-up time, the residents' activity time, and odor complaints from residents. Complex odor and 22