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Research article

Identification, quantification and treatment of fecal odors released into the air at two wastewater treatment plants

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A B S T R A C T

Odorous emissions from wastewater treatment plants (WWTPs) are an annoyance for neighboring communities. This article, for the first time, quantitatively reports on an evaluation of the presence of fecal odorants identified in air samples from two exemplary WWTPs by the odor profile method (OPM) and chemical analysis. The fecal odorants indole and skatole were identified by Gas Chromatography-Mass Spectrometry. The odor threshold concentration of skatole was determined to be 0.327 ng/L (60 pptV) in Teflon Bags by an expert panel. Skatole was found to be the primary chemical leading to fecal odor, due to its odor concentration to odor threshold concentration ratio that ranged from 2.8 to 22.5. The Weber-Fechner law was followed by pure skatole, but was not applicable when there was a mixture of fecal odorants and other odorant types present in WWTP air emission samples. This is probably caused by antagonism with other odorant types. Several existing odor control treatment methods for fecal odorants were evaluated at different wastewater treatment operations at two WWTPs by the OPM and chemical analysis for indole and skatole. Chemical scrubbing and biofiltration performed best in removing fecal odors among current control technologies.

1. Introduction

Odorous compounds can be released into surrounding residential neighborhoods by wastewater treatment plants (WWTPs), causing an odor nuisance. Release of odors is typically associated with improperly covered process areas, insufficient negative pressure, and inadequately treated foul air. Insufficient control of malodors may impact the reuse of treated sewage and worsen the relationship between WWTPs and surrounding communities (Lin et al., 2001). The control of odorous emissions has become a major challenge in the wastewater treatment industry.

In order to control odors, it is necessary to have a consistent language for their definition and an understanding of the possible chemical compounds responsible. The Wastewater Odor Wheel and the odor profile method (OPM) (Burlingame, 1999; Burlingame et al., 2004; Suffet and Rosenfeld, 2007; Burlingame, 2009) were developed to categorize typical wastewater odors and their intensities by odor panels as well as to help identify the chemicals that define those odors characteristics by chemical analysis techniques.

Indole (fecal/rubbery odor) and skatole (fecal/manure odor) are typical fecal odor-causing compounds (Lebrero et al., 2011). The odor threshold concentrations (OTC) of indole in water was reported as 0.1–14 μg/L (Lasaridi et al., 2010) and the OTC of skatole in water was reported as 1 μg/L (Malleret et al., 2001). However, the OTC of skatole in air has been reported to be as low as 0.004 ng/L in air (0.75 pptV) (Ruth, 1986). A very low method detection limit is required for analytical techniques to detect these compounds in air, which makes air analysis challenging.

Indole and skatole in aqueous phase have been reported in wastewater influent and primary effluent to be from 430 to 700 μg/L in a literature review by Hwang et al. (1995). Godayol et al. (2011) detected indole at 90 μg/L and skatole at 10 μg/L from wastewater influent. Islam et al. (1998) detected indole at concentrations between 6 and 61.8 μg/L and skatole at 4.83 μg/L in the aqueous phase from a sludge treatment process. However, there are only a few studies that deal directly with their presence and control in air. A solid phase microextraction (SPME) coupled to GC-MS method was developed to detect indole and skatole in air samples from WWTPs (Godayol et al., 2013; Razote et al., 2002). However, indole and

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skatole were not detected in air samples from the influent, biologic treatment and sludge pretreatment areas of the WWTP with a working range from 0.8 to 40 ng/L in air (Godayol et al., 2013). The understanding of fecal odors in the air escaping from WWTPs is critical to the development of air treatment methods to control these compounds and to enable the modeling of the impact of the odor at the plant fence line and in the surrounding communities.

Indole and skatole are formed biochemically by anaerobic degradation of the amino acid tryptophan (Yakoyama and Carlson, 1979). The primary metabolite of tryptophan is indole. Skatole was found to be produced from tryptophan and indoleacetic acid (IAA) in the intestinal tract, rumen, and swine manure (Yakoyama et al., 1977; Whitehead et al., 2008). IAA is formed by deamination of tryptophan and subsequently decarboxylated to skatole (Fig. 1). The production of skatole is associated with low-GC content bacteria, including the Clostridium and Bacteroides (Cook et al., 2007).

The first objective of this study was to relate fecal wastewater odors in air and their intensities, as measured by odor panels, and to identify the fecal odorant(s), in air by GC-MS. A second objective was to measure the OTCs of fecal odor causing compounds and to try to determine a correlation between the odor intensity and concentration of these fecal odorants. This study was part of the Orange County Sanitation District's (OCSD) Odor Control Master Plan for 2014. The OCSD project's objective was to characterize the odors from different wastewater treatment processes and quantify suspected chemicals. The results will be used in future studies to design odor control technologies for the nuisance odors.

2. Experimental

2.1. Sample locations

Initially, air samples were collected for the Odor Profile Method (Curren et al., 2014; Vitko et al., 2014; Abraham, 2014) at 16 stations at Plant 1 from August to September, 2013 and 16 stations at Plant 2 from October to November, 2013 at the Orange County Sanitation District WWTPs in 10 L Tedlar bags for qualitative identification. Subsequently, Teflon bags were used for quantitation as it was reported that Tedlar bags adsorbed Skatole and Teflon bags did not over the sampling to analysis time of 6 h (Boeker et al., 2014; Zhou et al., 2016).

The Orange County Sanitation District, a special district of the County of Orange, California, has a service area of 463 sq. miles containing 587 miles of sewers and serving a population of 2.5 million in two municipal wastewater treatment plants: Plant 1 located in the city of Fountain Valley has an average daily influent of 95 MGD and Plant 2 in the city of Huntington Beach has an average daily influent of 112 MGD. Both plants are adjacent to residential areas that occasionally become affected by odors.

The treatment facilities were sampled before and after odor control treatments to determine their effectiveness in reducing particular odorants (Vitko et al., 2014). There was a knowledge gap regarding fecal compounds. Thus, a goal of the OCSD project included the quantitation of compounds responsible for all odors including the fecal odor that comprised part of the total odor at the plant as measured by Olfactometry (AC'SCENT olfactometer by St. Croix Sensory Inc., Stillwater, MN). For quantitation of fecal odors, locations with high fecal odor intensities were sampled with Teflon bags and immediately delivered and analyzed within a maximum of 6 h.

2.2. Sensory evaluation by the odor profile method (OPM)

The OPM developed by Burlingame (1999) was used as the sensory evaluation of gas samples at UCLA by a trained odor panel. OPM is a modification of Standard Method 2170: the Flavor Profile Analysis Method (FPA) (APHA, 2012). The FPA Method has been used in the drinking water industry since 1980's to characterize odor sources and identify analytical methods to understand odor problems (Suffet et al., 1988). The only difference is that the sampling bag is opened to smell the air sample for the OPM whereas the headspace over the water is smelled for the FPA method. Tedlar bags were purchased from SKC Ltd. (Dorset, UK) and Teflon bags were purchased from Jensen Inert Products (Coral Springs, FL. USA).

The panelists were taught to identify multiple odor characters and their respective intensities in a single sample and to rate their particular odor intensity. The odor intensity was evaluated using the FPA Method's seven-point odor intensity scale (1, 2, 4, 6, 8, 10, 12), which has been shown to be equivalent to the butanol air odor intensity scale (Curren et al., 2014).

The intensity of an odor characteristic is a measure of its odor strength, which is related to the log of its concentration via the Weber-Fechner law Eq. (1) (Greenman et al., 2005; Muñoz et al., 2010; Suffet et al., 1995).

$$I = k \, \mathrm{Log} C/C_o \tag{1}$$

The intensity (I) is proportional to the logarithm (base 10) of the concentration (C) relative to a previous concentration (C_o). The average and standard deviation of intensity was calculated if 50% or more of panelists reported that odor character. If an odor character was reported by less than 50% of the panelists, the odor was reported as odor note without an intensity. The OTC is defined on the scale as an intensity of 1. Based upon the knowledge of the drinking water industry, an intensity of 4 was used to indicate where 50% of the general public could recognize the odor, which can be defined as an odor recognition concentration (ORC) (Suffet et al., 2008). A calculated odor intensity of 3 was suggested as the odor nuisance level where the more sensitive neighbors may start to complain. Fig. 2 shows the intensity scale for OPM analysis in terms of the Weber-Fechner Law derived from Eq. (1).

2.3. Odor threshold concentrations (OTCs)

The OTC is at an odor intensity level of 1 on the Weber Fechner

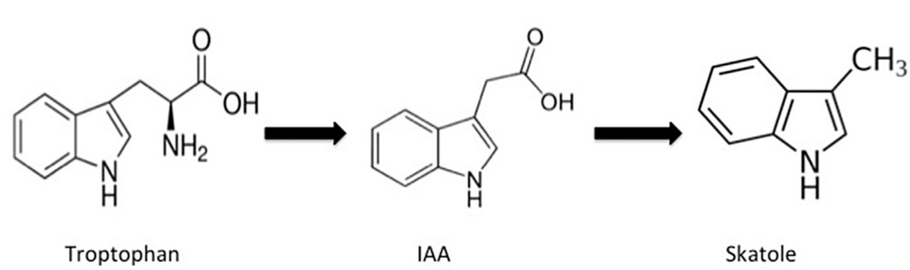

Fig. 1. Catabolic pathway for skatole.