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Determination of urine-derived odorous compounds in a source separation sanitation system

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ABSTRACT

Source separation sanitation systems have attracted more and more attention recently. However, separate urine collection and treatment could induce odor issues, especially in large scale application. In order to avoid such issues, it is necessary to monitor the odor related compounds that might be generated during urine storage. This study investigated the odorous compounds that emitted from source-separated human urine under different hydrolysis conditions. Batch experiments were conducted to investigate the effect of temperature, stale/fresh urine ratio and urine dilution on odor emissions. It was found that ammonia, dimethyl disulfide, allyl methyl sulfide and 4-heptanone were the main odorous compounds generated from human urine, with headspace concentrations hundreds of times higher than their respective odor thresholds. Furthermore, the high temperature accelerated urine hydrolysis and liquid–gas mass transfer, resulting a remarkable increase of odor emissions from the urine solution. The addition of stale urine enhanced urine hydrolysis and expedited odor emissions. On the contrary, diluted urine emitted less odorous compounds ascribed to reduced concentrations of odorant precursors. In addition, this study quantified the odor emissions and revealed the constraints of urine source separation in real-world applications. To address the odor issue, several control strategies are recommended for odor mitigation or elimination from an engineering perspective.

Introduction

In recent years, the concept of source separation system has attracted increasing attention due to the improvement in the wastewater management practice (*e.g.*, water conservation, biogas production, and nutrient recovery) (Bracken et al., 2007). The key to a source separation system is the use of urine diverting toilet, which can effectively separate the human excreta into yellow water (urine) and brown water (feces). The source-separated urine can be utilized in agriculture after sufficient storage, or nutrient (NPK) recovery by engaging different urine treatment processes (Maurer et al., 2006; Larsen et al., 2009; Zhang et al., 2014).

Unlike the conventional wastewater treatment plants (WWTP), source separation-based facilities are designed to deal with wastewater streams with distinct physicochemical characteristics and potentially confront with more severe odor issues. Odor emissions have been investigated in WWTP, animal farms, food-processing plants, *etc.* (Easter et al., 2005; Kleeberg et al., 2005; Van Groenestijn and Kraakman, 2005).

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However, there is limited information on odor emissions derived from urine source separation systems. The odorous compounds present in urine could be influenced by gender, age, diet, physiological and hormonal status, and use of drugs (Edman and Brooks, 1983; Guernion et al., 2001). Some studies were conducted to identify the odorous substances that could serve as potential indicators for diseases or specific metabolic syndromes (Bolodeoku and Donaldson, 1996). Hiroshi et al. (2001) determined the malodorous substances derived from human excreta (feces and urine) using thermal-desorption cold-trap and gas chromatography–mass spectrometry. Their results showed that fatty acids were the main malodor-causing substances, and other odorous compounds included sulfur-containing compounds (hydrogen sulfide and methyl mercaptan) and nitrogen-containing compounds (ammonia, pyridine, pyrrole, indole, skatole and trimethylamine). It is important to recognize that odor could be an important issue of source separation systems because odor-related complaints could change the public acceptance of those systems.

Based on the source separation concept, systematic investigations on urine management were conducted in our previous studies. Urine hydrolysis was studied in open systems showing that hydrolysis process could be accomplished in 2 days at high temperature (35°C) by adding 20% stale urine (Zhang et al., 2013). In that study, it was also proven that electrical conductivity could serve as an ideal indicator for urine hydrolysis monitoring. Further studies indicated that phosphorus recovery from the hydrolyzed urine could be achieved through induced struvite precipitation using seawater as magnesium source, while nitrogen harvesting was accomplished by air stripping and subsequent acid adsorption (Liu et al., 2013, 2014). Afterwards, hydroponic system was applied to further polish the urine effluent in order to meet the discharge standards (Yang et al., 2015). Despite of the very promising results, the urine treatment systems were subjected to odor emissions which could obstruct real-world applications. The emitted compounds were generally non hazardous to human health, but unpleasant conditions were formed in the open treatment lines, especially when high temperatures were applied. It is therefore necessary to determine the odor emissions from source-separated urine in order to develop effective odor control strategies.

The main purpose of this study was to determine, both qualitatively and quantitatively, the odorous substances in the headspace of urine storage tank during the hydrolysis process. The effects of temperature, dilution, stale/fresh urine ratio on the odorous emissions were investigated as well. The findings from this study could provide a useful reference for the odor control, while several methods are proposed to mitigate or eliminate odorous emissions.

1. Materials and methods

1.1. Chemicals

All reagents used in this study were of analytical grade. Six odorant standards including dimethyl disulfide (DMDS), allyl methyl sulfide (AMS), 4-heptanone, allyl methyl disulfide (AMDS), methyl propyl disulfide (MPDS), and menthol were provided by Sigma-Aldrich (Singapore) with high purity (98%).

1.2. Batch experiments

Fresh urine was collected from 25 healthy adults and stored in a sterile plastic tank. Batch experiments were carried out in glass carboys (5 L) to monitor the urine hydrolysis process and determine the odorous emissions under different conditions, including two temperatures (23, 35°C), three dilution factors (no dilution, 1:2, 1:5) and fresh/stale urine ratio (4:1). Each carboy was loaded with 1 L of urine solution. The urine-loaded carboys were then capped with a liquid sampling port and two gas sampling outlets as well as one gas inlet.

1.3. Chemical analysis of urine samples

The ammonium concentration in urine samples was measured using a DR 2800 spectrophotometer based on the salicylate method (Hach, USA). The pH-value was measured with a D-54 pH meter (Horiba, Japan). The volatile fatty acids (VFA) in urine samples were determined by gas chromatography (Agilent Technologies 7890A, USA) equipped with a flame ionization detector and a DB-FFAP capillary column (30 m × 0.32 mm i.d. × 0.50 μm film thickness, J&W Scientific, Agilent). The collected urine samples were first filtered through 0.45 μm cellulose acetate membrane filters and the injection volume was 1 μL. At least two parallel replicates were engaged throughout the study for quality assurance.

1.4. Odor quantification analysis

Odorous gas sample was actively collected from the carboy headspace using two digital air sampling pumps (GilAir Plus, USA) operated at a flow rate of 100 mL/min. A total volume of 1 L gas sample was aspirated and passed through a stainless steel sampling tube packed with 130 mg Tenax TA adsorbent (Perkin Elmer, USA).

Gas analysis was then carried out with a thermal desorber (TD-100, Markes International, Llantrisant, UK) followed by gas chromatography–mass spectrometry (TD-GC/MS) (7890A/5975C, Agilent). A two-stage desorption process was applied to desorb the target compounds from the Tenax TA sorbents. The desorption temperature was set at 280°C for 10 min, and then at 320°C for 5 min. The flow rate of carrier gas (N_2) was held at 100 mL/min and the cold trap temperature was kept at 0°C. The split ratios for sample injection were adjusted between 1:10 and 1:200 according to the concentrations of target compounds collected in the sampling tubes. The oven temperature program was 40°C hold for 10 min, ramping to 250°C at 10°C/min and held for 5 min. A DB-5 ms capillary column (30 m × 0.25 μm i.d., thickness 0.25 mm) was used to effectively separate the target compounds with a helium flow rate of 1.2 mL/min. The MS was operated in electronic ionization (EI mode) and scan mode. The target compounds were quantified with external calibration curve established over a range of standard concentrations: 22, 44, 110, 220 and 440 mg/L. 2 μL of standard solution was injected into the Tenax TA sorbent with 100 mL/min carrier gas (N_2) for 5 min.

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