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Characteristics of pollutant gas releases from swine, dairy, beef, and layer manure, and municipal wastewater

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ABSTRACT

Knowledge about characteristics of gas releases from various types of organic wastes can assist in developing gas pollution reduction technologies and establishing environmental regulations. Five different organic wastes, i.e., four types of animal manure (swine, beef, dairy, and layer hen) and municipal wastewater, were studied for their characteristics of ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and sulfur dioxide (SO_2) releases for 38 or 43 days in reactors under laboratory conditions. Weekly waste additions and continuous reactor headspace ventilation were supplied to simulate waste storage conditions. Results demonstrated that among the five waste types, layer hen manure and municipal wastewater had the highest and lowest NH_3 release potentials, respectively. Layer manure had the highest and dairy manure had the lowest CO_2 release potentials. Dairy manure and layer manure had the highest and lowest H_2S release potentials, respectively. Beef manure and layer manure had the highest and lowest SO_2 releases, respectively. The physicochemical characteristics of the different types of wastes, especially the total nitrogen, total ammoniacal nitrogen, dry matter, and pH, had strong influence on the releases of the four gases. Even for the same type of waste, the variation in physicochemical characteristics affected the gas releases remarkably.

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1. Introduction

Gas release is a process of gases transferring from the immediate surface of wastes (e.g., manure or wastewater) into a free air stream. Gas emission is a process of gases emanating from an enclosure (e.g., an animal building) and entering the outdoor atmosphere (Ni, 1999). Under transient conditions or when there are gas sinks in the enclosure (e.g., a biofilter), the quantity of gas release does not equal that of gas emission. Ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and sulfur dioxide (SO_2) are among the major pollutant gases released from animal manure and municipal wastewater. Excessive quantities of NH_3 emitted from livestock and poultry farms could have negative impact on environment and ecosystems. Ammonia has also been reported to relate to livestock odor annoyance and health outcomes in residential outdoor environment (Qamaruz-Zaman and Milke, 2012; Blanes-Vidal et al., 2012b, 2014), although it is not the main component of odorants. Release of CO_2 can alter the manure surface pH and accelerate NH_3 emission from the manure (Ni et al., 2000). Hydrogen sulfide is a prominent gaseous constituent in animal buildings and manure storage (Hooser et al., 2000). It has been considered the most dangerous gas from livestock production systems and was responsible for deaths of many animals and farm workers at animal facilities (e.g., Beaver and Field, 2007; Oesterhelweg and Puschel, 2008). Concentrations of H_2S ranging from 0 to 2 ppm (part per million) were reported in animal buildings (e.g., Clark and McQuitty, 1987; Ni et al., 2002, 2012). However, when manure in deep-pit is agitated by mixing during pit empting, paramount increases in H_2S releases can occur (Hoff et al., 2006; Blanes-Vidal et al., 2012). Sulfur dioxide (SO_2) emitted to the atmosphere can form sulfuric acid (H_2SO_4) and cause acid rain. Very little information about SO_2 from agriculture wastes has been reported.

Knowledge about quantification and release behavior of gases from various waste sources is important not only for establishing environmental regulations, but also for developing gas emission mitigation technologies. However, direct comparison of the characteristics of gas releases from different pollution sources has not been found in the literature.

Gases are produced in organic wastes under biological decomposition, which can convert organic matters into ionized substances (e.g., NH_4^+, HCO_3^-) or free gases (e.g., NH_3, CO_2) in the wastes. Several mechanisms or processes of gas release have been reported in the literature (Ni et al., 2009). In the convective mass transfer release process, dissolved gases transfer from the liquid wastes to the air stream due to difference in partial pressures between the liquid surface and the free air stream (Ni, 1999). In the bubble-release process, gas bubbles aggregate, ascend, and release to the free air stream after breaking at the liquid surface (Ni et al., 2009; Blanes-Vidal et al., 2010; Blanes-Vidal and Nadimi, 2011). Different release mechanisms are responsible for different gases. As reported by Ni et al. (2009), convective mass transfer governed NH_3 release due to its high solubility, while bubble-release played an important role in the releases of H_2S, SO_2, and CO_2.

The chemical dissociation reactions that occur in the liquid wastes related to NH_3, CO_2, H_2S, and SO_2 can be expressed in Eqs. (1)–(6).

$$NH_4^+ \rightleftharpoons NH_3 + H^+ \quad (1)$$

$$CO_2 + H_2O \rightleftharpoons HCO_3^- + H^+ \quad (2)$$

$$HCO_3^- \rightleftharpoons CO_2^{2-} + H^+ \quad (3)$$

$$H_2S \rightleftharpoons HS^- + H^+ \quad (4)$$

$$2HS^- + 3O_2 \rightleftharpoons 2HSO_3^- \quad (5)$$

$$HSO_3^- + H^+ \rightleftharpoons SO_2 + H_2O \quad (6)$$

It has been known that pH in the liquid waste is controlled by a few major buffer components, including total inorganic carbon ($[TIC] = [CO_2] + [HCO^{3-}] + [CO_2^{2-}]$), total ammoniacal nitrogen ($[TAN] = [NH_3] + [NH_4^+]$), and total acetic acid ($[TAc] = [HAc] + [Ac^-]$) (Sommer and Husted, 1995; Sommer and Sherlock, 1996). The pH and concentrations of buffer components (TAN, TIC, and TAc) are different in different types of wastes, which can affect gas releases. In a stored liquid waste system, the microbial degradation and gas release can change the waste characteristics and pH over time (Moller et al., 2004). For instance, oxic degradation of organic matter can reduce the content of acids in solution and thereby increase pH; and anoxic processes can contribute to the formation of organic acids (e.g., VFA) and thereby reduce pH. Besides, releases of acidic gases (e.g., H_2S, CO_2) tend to increase the pH in surface liquid layer; and releases of basic gases (e.g., NH_3) tend to decrease the pH in it (Sommer and Sherlock, 1996). Conversely, change in waste pH can affect the releases of NH_3, CO_2, H_2S, and SO_2. Gas releases, and waste characteristics and pH present a dynamic equilibrium when the liquid waste is under steady state conditions. However, disturbances, such as animal manure dropping into the pit or rain falling into outdoor waste storage tanks, can break the dynamic equilibrium and result in transient gas releases (Blanes-Vidal et al., 2012a).

Gaseous emissions from livestock production facilities are affected by several factors including animal, temperature, ventilation, and farm operation (Arogo et al., 2003). Emissions of gases from different animal production systems under field condition are hardly comparable; and the effects of some environmental parameters (e.g., air flow and temperature) on the emissions are difficult to determine (Saha et al., 2011). Therefore, gas releases from different wastes and their characteristics can be better investigated under controlled laboratory conditions.

Studies related to gas emissions from waste storage have mainly been focused on NH_3 from swine manure (Ni, 1999; Arogo et al., 2003; Gay et al., 2003; Sommer et al., 2007; Cortus et al., 2008), dairy manure (Patni and Jui, 1991; Sommer et al., 2007; Mathot et al., 2012), and layer manure (Ni et al., 2010); CO_2 from swine manure (Ni et al., 1999; Moller et al., 2004; Sommer et al., 2007) and dairy manure (Mathot et al., 2012); and H_2S from swine manure (Arogo et al., 2000; Clanton and Schmidt, 2000; Gay et al., 2003; Hoff et al., 2006;