Atmospheric Environment 190 (2018) 43–52

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Ammonia emissions from an in-ground finisher hog manure tank

Richard H. Grant*, Matthew T. Boehm

Department of Agronomy, Purdue University, USA

ARTICLE INFO

Keywords:
Livestock emissions
Ammonia emissions

ABSTRACT

A large fraction of emitted and ultimately deposited ammonia (NH_3) originates from swine waste storage. Understanding the factors that influence these emissions is important in determining how to mitigate NH_3 loading of the atmosphere. Hog manure is stored in slurry pits, tanks, or lagoons. Ammonia emissions from a ground-level mid-western hog finisher manure tank collecting manure from a mean of 3508 animals was measured for 8–20 d each quarter of the year for two years. Forty of the 164 measurement days had sufficient measurements to represent entire days. These daily emissions averaged 0.44 g NH_3 $m^{-2}h^{-1}$ (53.1 g d^{-1} AU^{-1}, 7.2 g d^{-1} hd^{-1}: AU = 500 kg animal mass, hd = 1 animal) with maximum emissions of 1.62 g NH_3 $m^{-2}h^{-1}$ (194.2 g d^{-1} AU^{-1}, 26.4 g d^{-1} hd^{-1}). Emissions from the tank were greater on an area basis but comparable on an animal basis relative to emissions from much larger anaerobic lagoons. Emissions were correlated with air temperature and manure composition, but not wind speed or friction velocity- probably due to the turbulence created by the tank structure under all winds. Crusting of the manure surface in the tank corresponded with a non-significant 10% increase in NH_3 emissions. A model of the tank emissions, based on nominal nitrogen loading rates from the literature and taking into account the configuration of the circular tank, had a mean bias error of 0.01 g NH_3 $m^{-2}h^{-1}$ (0.9 g d^{-1} AU^{-1}, 0.1 g d^{-1} hd^{-1}) and a root mean square error of 0.26 g $NH_3m^{-2}h^{-1}$ (31.6 d^{-1} AU^{-1}, 4.3 g d^{-1} hd^{-1}). Additional emissions measurements from such ground-level manure storage tanks with greater documentation of the manure liquid composition are needed to verify the modeling approach.

1. Introduction

Animal agriculture is a significant source of ammonia (NH_3) emitted into the atmosphere. The emission of NH_3 contributes to long-term global warming through rapid deposition and subsequent production of N_2O (USEPA, 2011). Ammonia emissions also contribute to the formation of $PM_{2.5}$ (USEPA, 2011). Agricultural operations are required to report emission that exceed 220 kg d^{-1} in compliance with the Emergency Planning and Community Right-To-Know Act in the United States (Centner and Patel, 2010). Emissions from manure storage facilities are a significant fraction of the total farm NH_3 emissions. Manure from hog operations is typically stored in a lagoon, a pit/tank, an above-ground tank, or a below ground concrete tank. Manure storages are designed, in part, on the basis of manure loading over the maximum storage period (ASAE, 1998; USDA, 2016). Since the manure loading depends on the transfer of excreted manure, the number and mass of the hogs excreting is important in defining the necessary size of the storage. While anaerobic lagoons are sized to account for the manure loading and sludge storage for many years, dilution water to encourage bacterial activity, and storage of precipitation less evaporation; manure storage tanks need only handle the manure loading and sludge storage for less than one year, and storage of precipitation (less evaporation) (Worley, 2015). Consequently, the storage of the same manure loading requires much less volume for a tank than for an anaerobic lagoon.

Szögi et al. (2005) measured emissions from an anaerobic hog finishing waste lagoon of 0.156 g $m^{-2}h^{-1}$ (9.75 g NH_3 hd^{-1} d^{-1}) during nine measurement days distributed across a year. Shores et al. (2005) measured NH_3 emissions of 0.60 g $m^{-2}h^{-1}$ (44.1 g hd^{-1} d^{-1}) from an anaerobic lagoon on one day during July at a finishing farm in North Carolina. Zahn et al. (2001) measured average emissions of 0.66 g $m^{-2}h^{-1}$ (22.7 g NH_3 hd^{-1} d^{-1} from an anaerobic lagoon at a Missouri finishing operation during a 14-day measurement campaign in

---

Abbreviations: a, air over tank; AU, 500 kg animal mass; b, laminar air; BG, background; bLS, backward Lagrangian stochastic; F, fraction of loading; g, conductance; H, Henry's coefficient; hd, 1 animal; K, bulk exchange coefficient; LM, live mass; L, volumetric loading rate; LIQ, liquid; MDL, minimum detection limit; NAEMS, National Air Emissions Monitoring Study; OP, optical path; RPM, Radial plume mapping; s, surface; SA, surface area; Sc, Schmidt number; SD, standard deviation; TDLAS, tunable diode laser absorption spectrometer; TS, total solids; u_*, friction velocity; V, volume; β, Van't Hoff temperature coefficient

* Corresponding author. 915 W. State St, West Lafayette, IN, USA.
E-mail address: rgrant@purdue.edu (R.H. Grant).

https://doi.org/10.1016/j.atmosenv.2018.07.009
Received 4 March 2018; Received in revised form 5 July 2018; Accepted 7 July 2018

Fig. 1. Configuration of study site. Locations of the five retroreflectors on each cardinal direction from the tank are indicated with a prefix of direction from the tank. Reroreflectors 3, 4, and 5 were mounted on towers while 1 and 2 were on tripods. Scanning TDLAS units are indicated by 'TS'. Image from GoogleEarth®.

late summer and early fall. Grant et al. (2016) measured emissions from anaerobic lagoons at finishing farms in two states, finding average daily emissions of 0.18 $g\,m^{-2}h^{-1}$ (104 g AU^{-1} d^{-1}, 16.1 $g\,hd^{-1}$ d^{-1}) at a farm in Oklahoma based on 59 d of measurements across two years and of 0.08 $g\,m^{-2}h^{-1}$ (36 g AU^{-1} d^{-1}, 4.4 $g\,hd^{-1}$ d^{-1}) at a farm in North Carolina based on 16 d of measurements across two years.

The type of the manure storage facility may contribute to the differences in emissions. A laboratory study showed that NH_3 emissions decreased as the surface area (SA) to volume (V) ratio of a constant volume of manure decreased from 0.99 to 0.03 m^2m^{-3} (Sievers et al., 2000). Sievers et al. (2000) attributed this to reduced NH_3 desorption and not initial nitrogen content. Anaerobic lagoons that were part of the NAEMS had SA:V ratios of 0.25–0.4 m^2m^{-3} (Grant et al., 2016) while storage tanks have a SA:V ratio of 0.1 m^2m^{-3} (Grant and Boehm, 2010a, 2010b) to 0.3 m^2m^{-3} (Sommer, 1997). Muck and Steenuis (1982) modeled the emissions and found that decreasing SA:V results in decreased emissions for a fixed desorption rate because the depth of manure added each day to a tank increases which increases the distance within the manure that the NH_3 must diffuse to be emitted at the surface. Consequently manure in tanks would be expected to emit less NH_3 than that in lagoons given identical manure composition.

The composition of the manure influences NH_3 emissions. Total ammoniacal nitrogen (TAN = NH_3 + NH_4^+) in the storage tank increases due to microbial mineralization of organic N in the manure and decreases through immobilization with organic matter, nitrification and denitrification (Sommer et al., 2006). Ni et al. (2010) found in a laboratory study that diluting manure from an average of 6.4% dry matter (DM) to 3.4% DM by increasing manure volume and not changing the total N content increased NH_3 emissions. Anaerobic lagoons typically have less than 1% DM while slurry storage tanks have up to 9% DM (USDA, 2008). Tank storage should have reduced NH_3 desorption due to the low SA:V (Sievers et al., 2000) and reduced emissions from high DM manure (Ni et al., 2010) compared to lagoons.

This is not what has been observed in the field. Only a few measurements of NH_3 emissions from tank manure storages have been reported (Sommer, 1997; Gay et al., 2003). Gay et al. (2003) measured the NH_3 emissions from a hog finishing farm manure tank using a low speed wind tunnel on the liquid surface on four days and found emissions ranging from 0.306 $g\,m^{-2}h^{-1}$ to 2.43 $g\,m^{-2}h^{-1}$ with an average of 1.44 $g\,m^{-2}h^{-1}$. Sommer (1997) found emissions of up to 1.5 $g\,m^{-2}h^{-1}$ using the integrated horizontal flux measurement method for an uncovered slurry tank in Denmark with much higher total N content than typical anaerobic lagoons (e.g. Grant et al., 2013a, 2013b). These two tank emission studies suggest emissions from tanks are much larger than from anaerobic lagoons on an area basis. Sommer (1997) suggested that the relatively high NH_3 emission rates from tanks in the field may be due to either a greater NH_3 concentration gradient between the liquid and air overlying the liquid or an enhanced transfer rate. Unfortunately, while N content of the manure was reported, there was no information to express the emissions on an animal basis. It is also possible that the exposure of the tank at the ground surface may contribute to the emissions in a similar manner that the configuration of stomatal pores on a leaf influences mass transfer between the leaf and the atmosphere (Parlange and Waggoner, 1970); Montieth and Unsworth, 1990).

Crusting of the surface of the stored manure commonly occurs as the DM increases to up to 6% (Wood et al., 2012). Increases in DM and the formation of crusts can occur as increased air temperatures increase evaporation of the stored manure (Misselbrook et al., 2005; Smith et al., 2007). Deeper tanks, with smaller SA:V ratio were found to increase incidence of crusting compared to shallow tanks through providing greater DM under the exposed surface (Smith et al., 2007). Crusting has been shown to decrease NH_3 emissions (Sommer et al., 1993; Olesen and Sommer, 1993; Misselbrook et al., 2005; Wood et al., 2012). It is presumed that the decrease in emissions is largely a result of increased resistance to diffusive transport from the liquid to the overlying air (Sommer et al., 1993, 2000; Olesen and Sommer, 1993). However nitrification, denitrification, NO_3^- leaching may also contribute to the