TECHNIQUE FOR DETERMINATION OF AMMONIA EMISSIONS IN URINE-DIVERTING WASTEWATER SYSTEMS

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ABSTRACT

In systems that collect human urine separately, there is a risk for high losses of nitrogen via ammonia emissions. In systems for animal urine collection, 25-75% of the nitrogen is estimated to be lost. To estimate the ammonia emissions from a sewage system with urine collection, CO_2 was used as tracer gas. A system that continually measured the CO_2 level was installed, and protected from the corrosive ammonia via an acid trap. Two systems were investigated, showing that appropriate design of the system can decrease the ammonia emissions from 1-6% to 0.01-0.2%.

Keywords*: ammonia emission, gas emissions, measurement technique, urine collection system.*

INTRODUCTION

Urine diverting wastewater systems are used to lower the load of nutrients to water treatment works and water recipients and to produce an clean organic fertiliser. Several environmental systems analyses have concluded that supplementing the conventional sewage system with urine separation is environmentally advantageous, decreasing both the eutrophication and the use of energy. However, ammonia emission has been a major uncertainty in these studies. This emission could potentially be large and thus change the conclusion, since ammonia causes both acidification and eutrophication.

During collection and storage of animal urine, the ammonia emissions are often large. Normally 25-75% of the total nitrogen content is estimated to be lost as ammonia. This high emission rate is because of the high pH of the urine and because it is collected and stored in open systems.

In an ammonia/ammonium solution such as urine, dissolved NH_3 and NH_4^+ are in equilibrium with each other. The dissolved NH_3 in the liquid is also in equilibrium with NH_3 in the gas above the liquid. A high pH in the liquid therefore leads to a high equilibrium concentration of ammonia in the gas above. If this gas is exchanged, ammonia is lost and new ammonia is then emitted from the liquid to reach equilibrium concentration in the gas. Therefore, the potential ammonia emission can be calculated from the number of gas changes above the liquid phase.

The aim of the present study was to develop a method for determining the ammonia loss in urine collection systems.

METHODS

The measurement technique developed was based on the fact that the collection of human urine is performed in closed systems, mainly in subsurface tanks. Carbon dioxide was identified as an appropriate gas for determination of the air exchange rate in the tanks, as it is a much cheaper gas than the best alternative (SF_6) used by others (Scholtens et al. 2004). Liao and Bundy

(1995) claim that the high solubility of the gas in liquid can have an effect on the monitoring of the gas, as undetectable metabolites can be formed and the carbon dioxide can react with ammonia to form ammonia amide carbonate (CO_2 (g) + 2 NH_3 → NH_2COONH_4 (s)). Therefore, the accuracy of the method was successfully tested in a completely sealed small laboratory-scale system (25 litre tank with 5 litres of urine) to ensure that the CO_2 decrease was not caused by absorption into the urine. In addition, to minimise the contact area between the gas and the urine in the full-scale system, and thereby the risk for absorption of the CO_2 into the liquid, the surface of the liquid was covered with vegetable oil and a plastic sheet. The CO_2 concentration was measured using an infrared gas analyser (Telaire 1050™) digitally logged every minute. For calibration, concentrations were measured by GC analysis of samples manually extracted at preset intervals. The GC analysis was performed in a packed steel column with an oven temperature of 35°C (injector 120°C; detector 250°C), using helium as the carrier gas. After passage through the column, the CO_2 was analysed using a catalytic reaction with a nickel electrode in a system called the Methanizer (Börjesson and Svensson, 1997) followed by a flame ionisation detector. These pre-trials showed no reduction of CO_2 in the system during one week. To ensure that no ammonia could enter the gas analyser, the gas was cleaned in a 7M H_2SO_4 acid trap (Figure 1).

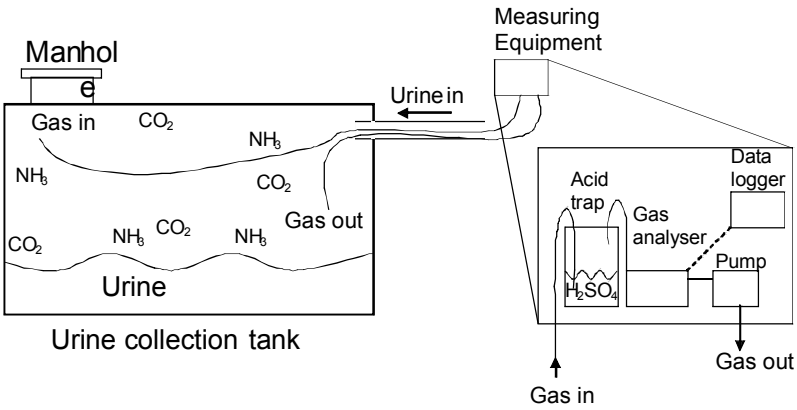

***Figure 1**. The design of the gas measurement system, where the concentration of CO_2 was constantly monitored.*

The ammonia concentration in the gas phase of the tank was determined and then PE-pipes connected to the measuring equipment were installed (Figure 1). CO_2 was added to a level of 5-6000 ppm in the gas phase of the tank and thoroughly mixed with a fan. The CO_2 level in the tank was monitored until the surrounding level was reached or for a maximum of seven days. Samples for GC analysis at the laboratory were taken manually after 0.5h, 1h, 5h, 1d, 3d and 7 days.

The measurements were performed in two systems, one where the urine was added through pipes in the top of the tank (open system, OS), allowing ventilation through the system via the 3 incoming pipes. The second system investigated was the same system after conversion to bottom filling (closed system, CS), thereby decreasing the ventilation.

Estimation of potential ammonia loss

The initial CO_2 content C_o was set by addition of CO_2(g). If C is the CO_2 content at the time t, the ventilation flow is Q and the CO_2(g) content in the incoming air is C_s, the change in CO_2

content in the tank is given by the following equation:

To solve that differential equation, the following substitution is made

$$\frac{dC}{dt} = -\frac{Q}{V}(C - C_s) \qquad (1)$$

$K = C\text{-}C_s$ (2) which means that $\frac{dK}{dt} = \frac{dC}{dt}$ (3)

Inserting equations 2 and 3 into 1 gives $\frac{dK}{dt} = -\frac{Q}{V}K$ (4)

The solution to that differential equation is $K = K_0 e^{-\frac{Q}{V}t} = K_0 e^{-Gt}$ (5)

where G is the number of gas exchanges per unit time, i.e. the number of times the gas has been changed per unit time.

RESULTS AND DISCUSSION

The correlation between the CO_2 concentration measured by the digital gas analyser and the GC analysis at the laboratory was good (Table 1), proving that the continuous analysis was accurate. No correlations were obtained in the initial analysis of trial 1 (Table 1), the probable reason for this being that carbon dioxide was lost during the month of storage before analysis. The gas samples were stored in evacuated 20ml test tubes, with 5ml liquid saturated with NaCl.

Table 1. *Correlation between the measurements by the GC analysis and the Telaire system during the first trials*

Date of analysis	Concentration according to GC ppm	Concentration according to Telaire ppm
17/5 Trial 1	2026	5640
20/5	871	860-890*
26/5 Trial 2	1920	1770-2200*
28/5	819	820
28/5 Trial 3	2125	2250
3/6	805	730

** the values given by Telaire fluctuated between these values during measurement.*

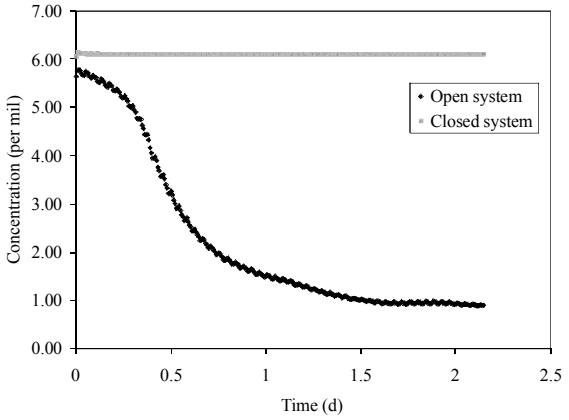

Figure 2. *The CO_2 concentration in the gas phase of urine collection tanks, with the two different system designs.*

The two different collection systems gave different reductions in CO_2 levels in the gas (Figure 2). The Open system, which allowed ventilation in the tank, had an fast reduction in carbon dioxide, while the closed system showed only little reduction: 10% during 50 days of measurement.

By using Equation 5 it was possible to calculate the number of air exchanges from the decrease in CO_2 concentration. The number of air exchanges was combined with the initial ammonia concentration in the gas phase to determine the ammonia loss in the system (Table 2). The low reduction of CO_2 in the closed system indicates that no or just a small amount CO_2 was adsorbed by the urine. Depending on the saturation of ammonia in the air, the ammonia losses from the system were estimated to be 1-6% in the open system and 0.01-0.2% in the closed system.

***Table 2**. Estimated ventilation of the urine tank when filled from the top (Open system, OS) and from the bottom (Closed system, CS).*

Filling strategy	Air exchanges/day	Ventilation* tank volumes/year	r^2 %	Estimated, during number of days measured
OS	2.07	756	99	Day 0.3-1.6
OS	2.76	1008	99	Day 0.4-0.8
OS	1.64	598	90	Day 9.2-10.8
CS	0.000008	0.003	0.2**	Day 0.2-18.0
CS	0.0008	0.3	29	Day 25.5-47.9

** The ventilation from emptying the tank is not included in this value.*
*** The low r2 value is caused by the almost horizontal line.*

CONCLUSIONS

CO_2 is a suitable, low priced tracer gas for measuring the air exchange rate in sewage systems where human urine is collected separately.

A portable IR analyser combined with a computer logger can be used for analysing the CO_2 levels with high accuracy at small time intervals.

Appropriate design, e.g. bottom filling of the system, can keep the ammonia losses during the collection phase very low.

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