Concentration of Urine from Fatteners combined with Ammonia Removal by Scrubbing Exhaust Air of a Pig House.

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Abstract

In the Dutch Hercules project feces and urine from pigs are collected separately and treated in two processes: feces are composted and urine is concentrated by water evaporation. Water unsaturated exhaust air from the pig house is used for evaporation in a packed bed scrubber. The urine is acidified with nitric acid to scrub ammonia from the air. In this way a concentrated N/K fertilizer is produced from urine and ammonia is removed from the pig house exhaust air.

Experiments were conducted using a pilot scale packed bed scrubber in an experimental pig house. The ammonia scrubbing efficiency and the evaporation rate were determined during one pig fattening round of 112 days.

The average composition of the collected pig urine was 4.4 g nitrogen/kg, 6.6 g potassium/kg and 0.03 g phosphorus/kg. The volume of the urine was reduced by a factor 6-7 resulting in a concentrate composition of 91.3 g/kg total nitrogen (including nitrogen added as nitric acid), 46.5 g/kg potassium and 0.2 g/kg phosphorus. The mean evaporation rate was 28 kg/day at inlet air conditions of 74% relative humidity and a temperature of 19°C. The inlet air of the scrubber was more humid (74% instead of 60%) than expected. This resulted in a evaporation rate that was below expectations. The ammonia scrubbing efficiency was determined 5 times and ranged from 68 to 95%. The efficiency decreased at higher salt concentrations of the urine.

KEYWORDS. ammonia, air scrubber, evaporation, pig waste, urine

Introduction

Pig production in the Netherlands relies substantially on the import of feeds from overseas and the use of residues from the food processing industry. Legislation restricts land application of minerals, and transport of pig slurry is costly. Volume reduction of slurry reduces costs of storage and transport and separation of minerals offers opportunities for sustainable land application. Therefore, methods are explored to produce concentrated fertilizers from pig waste on farms.

Reduction of the ammonia emission from pig houses is another environmental issue in relation to pig production. The exhaust air ammonia concentration of houses with finishing pigs on slatted floors averaged 12.9 mg/m^3 in a broad survey on housing types in the Netherlands (Groot Koerkamp *et al.*, 1998) . Aarnink *et al.* (1996, 1997) and Aarnink and Wagemans (1997) found ammonia concentrations of 4.7-12.2 mg/m^3 in a pig house with partially slatted floors.

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One of the aims of the Dutch Hercules project (Ogink *et al.*, 2000, Willers *et al.*, 2000) is to achieve simultaneous water evaporation and air scrubbing by exposing exhaust air of a pig house to acidified pig urine in a packed bed scrubber. Combination of these two functions in one system was subject to research in a pilot scale packed bed scrubber on an experimental pig farm. The aim was to measure the evaporation rate and the ammonia removal efficiency under field conditions. The results are presented and discussed in this paper.

MATERIALS AND METHODS

Set-up and operation

A pilot scale scrubber was situated on an experimental pig farm in Sterksel in the Netherlands. A detailed description of the pig house is given elsewhere (Ogink *et al.*, 2001). Evaporation capacity and ammonia scrubbing efficiency were tested during one pig fattening round with 80 pigs.The trial run was made in summer and fall and lasted 112 days. Ammonia removal efficiency was measured five times during this run.

The scrubber was operated using the electrical conductivity of the circulating liquid as a measure for the concentration factor. Concentrated acidified pig urine circulated across the packed bed in the scrubber. When the conductivity of the liquid reached a setpoint, liquid was pumped from the reservoir during a set time interval. After the removal of concentrate, fresh pig urine was added to a set level. The pH of the scrubbing liquid was adjusted to pH 4 by dosage of nitric acid (65% w/w) in the liquid outlet from the scrubber to the reservoir.

Initially there was a loss of small droplets from the scrubber exhaust. A mist eliminator was installed in the outlet pipe to overcome this problem.

Equipment

The pilot-scale scrubber was connected to the air exhaust of the pig house as shown in Figure 1. The scrubber was a PVC cylinder (h=2.4m; d=1.0m) and contained a packed bed (h=1.5m) of Rauschert Contact Rings (type Hiflow 50-0 PP; specific area 110 m^2/m^3) that rested on a stainless steel grid (10 mm) at a height of 0.5 m from the bottom of the cylinder. Air was introduced through a pipe (d=0.22m) sideways in the scrubber in a chamber underneath the packed bed. It left the scrubber through a pipe (d=0.22m) at the top.

An adjustable ventilator (Colasit CMV 225; 0,75 kW) with a maximum capacity of 2400 m^3/h, was used to blow air through the scrubber. The average flow during the trial run was 965 m^3/h. Measurements of the ammonia removal efficiency were done at 365 m^3/h (2 measurements) and 730 m^3/h (3 measurements).

A centrifugal pump (Grundfoss CRNE2-30; 0,37 kW; 0-5m^3/h) continuously pumped liquid from a 200 l reservoir to three spray nozzles (Steinen SSMW1406; spray angle 120^o) at 0.3 m above the bed. The liquid trickling from the packed bed was collected at the bottom of the scrubber and flowed back to the reservoir by gravity. Fresh pig urine was collected from a convex conveyor belt underneath the partly slatted floor that separates urine from feces (Ogink *et al.*, 2001).

Concentrated pig urine was removed from the reservoir and fresh pig urine was added using peristaltic pumps (1 l/min). The pig urine was sieved before use (mesh 0.5 mm) to remove the bigger particles.

The acid pump was a membrane pump (Prominent, Gala 1000).

Electrical conductivity (EC) of the liquid was measured with a WTW LF 340 conductivity meter. pH was determined with and a WTW pH 96 pH-meter. Both the EC- and the pH-sensor were placed in the pipe that supplied the nozzles with liquid. Temperature and relative humidity of air were measured with a sensor in the main exhaust of the pig house (Rotronic sensor; Hygromer series I-200).

The temperature of the liquid was measured (AD 592 temperature sensor) in the reservoir and at the bottom of the scrubber beneath the packed bed.

Ammonia concentrations in air samples from the inlet and the outlet of the scrubber were measured by scrubbing a sample of 60 l in an impinger filled with 70 ml of 0.05 M HNO_3. An air pump and flow controllers were used to keep the sample flow at 1 l/min. The ammonia concentration in the acid solution was determined in the laboratory.

Evaporation rate was determined by weighing the volumes of input urine and concentrate produced. Chemical analysis of pig urine and acid solution from the air samplers were made in the IMAG laboratory according to the Dutch Standards for Analysis of Waste and Wastewater (NNI, 1988).

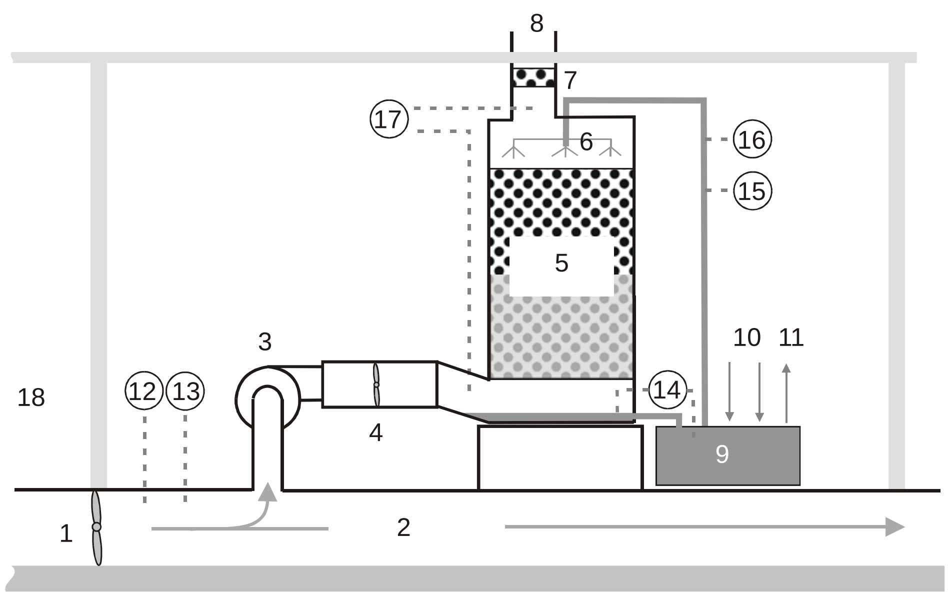

Figure 1: Pilot scale scrubber for combined concentration of pig urine and ammonia removal from pig house exhaust air; 1=fan, 2=main air exhaust of pig house, 3=centrifugal ventilator, 4=anemometer, 5=packed bed, 6=spray nozzles, 7=mist eliminator, 8=scrubber exhaust, 9=reservoir, 10=inlet fresh urine and acid, 11=outlet concentrate, 12= RH-sensor, 13= T-sensor, 14= T-sensor (liquid), 15= EC-sensor, 16= pH-sensor, 17=ammonia sampling ports, 18= pig house

RESULTS AND DISCUSSION

Air conditions and evaporation

It was assumed during experimental design that average conditions of the exhaust air from the pig house would be 60% RH and 20°C (Groot Koerkamp and Uenk, 1997). However, the exhaust air proved more humid (mean RH 74%). A pig diet of wet by-products resulting in a higher water excretion by the pigs was believed to be the main cause of the higher humidity (Ogink *et al.*, 2001). The evaporation rate of water from urine was negatively affected by the high humidity of the pig house exhaust air because it lowered the driving force for evaporation.

When the average relative humidity and dry bulb temperature of the inlet air are known, the maximum adiabatic evaporation rate in in the scrubber can be calculated, assuming that the air becomes completely saturated with water and that the exchange of energy with the environment of the scrubber is negligible. These calculations were made and the results are compared with the measured evaporation rate in Table 1. Since the measured evaporation rate did not reach the maximum value under adiabatic conditions, it was assumed that the exhaust air of the scrubber was not saturated. Using the measured evaporation rate, the calculated scrubber exhaust air relative humidity averaged 94%.

The air flow rate of 965 m^3/h can be considered as the average air flow for ventilation of 20 pigs (at 50 m^3 per pig per hour as measured in the trial). In the trial run, 2 kg of urine fraction were produced per pig per day (Ogink *et al.*, 2001). At an evaporation rate of 28 kg/d the volume reduction of the urine produced by these 20 pigs would be 70%.

Table 1: Air conditions and evaporation.

Parameter	**Value**
Air flow rate, m^3/h	965
Relative humidity ingoing air, %	74
Temperature ingoing air, °C	18.9
Evaporation (measured), kg/d Evaporation (measured), g/m^3 air	28 1.21
Maximum adiabatic evaporation (calculated), kg/d Maximum adiabatic evaporation (calculated), g/m^3 air	34 1.45

Ammonia absorption

The results of the ammonia removal measurements are shown in Table 2. Table 2 also gives the corresponding conditions of the scrubber liquid and the pig house ventilation air. All measured ammonia absorption efficiencies were higher than 65%. This proves that ammonia can be effectively scrubbed from air using concentrated acidified pig urine. There seems to be little effect of air flow on the ammonia removal efficiency.

Table 2: Results of ammonia removal measurements related to conditions of scrubber liquid and pig house exhaust ventilation air. EC= electrical conductivity, T= temperature, RH= relative humidity, NH3=ammonia

Scrubber liquid conditons			Conditions of ingoing air				NH_3 in exhaust air	
Flow Rate m^3/h	EC mS/cm	T °C	Air flow m^3/h	RH %	T °C	NH_3 Concentration mg/m^3	NH_3 Concentration mg/m^3	Removal Efficiency %
2.8	140	16.8	358	75	18.5	2.8	0.4	85
3.0	252	16.8	371	78	17.5	14.4	3.2	78
2.9	240	16.3	716	81	17.3	9.9	3.0	69
3.2	128	15.2	727	70	16.3	7.8	0.4	95
2.9	252	16.9	752	93	16.7	12.0	3.8	68

Salt effects

Mass transfer to and from liquids containing high concentrations of salts is likely to be affected by these salts. Both evaporation of water from the pig urine and absorption of ammonia from the air may be hampered by the salt concentration of the liquid. The electrical conductivity of the liquid phase was relatively low (128 and 140 mS/cm) when the highest ammonia removal efficiencies were observed. This indicates a negative effect of salt concentration in the liquid on the ammonia removal efficiency. A lower concentration of the urine by the scrubber has to be accepted if a high scrubbing efficiency is required.

Concentrate composition.

The results of chemical analysis of pig urine fed to the scrubber and of the concentrate produced are presented in Table 3. The pig urine fraction could be concentrated by a factor 6 in the pilot scale scrubber. The concentrate is a brown turbid liquid with a less pungent smell than the characteristic smell of pig slurry. The nutrient content of the most concentrated liquid was approximately 9% nitrogen, 5% potassium and 0.02% of phosphorus by weight. In a field test on potatoes this concentrate proved to be a good fertilizer as compared to a commercially available product (Van Geel, 2000). The concentrate contains many more elements than are shown in Table 3. Whether these elements could have negative effects on crop or soil quality is subject to further research. It must be clearly understood however, that these elements are also present in untreated pig slurry that is commonly used as a fertilizer in the Netherlands. The only exception is nitrate. Approximately 45% of the total nitrogen in the concentrated urine originated from the nitrate that was added during acidification.

Table 3: Composition of pig urine and acidified concentrated pig urine. TAN=total ammoniacal nitrogen.

		Fresh pig urine (*) (4 samples) Mean	(Range)	Concentrated acidified pig urine (6 samples) Mean	(Range)
Total nitrogen	g/kg	4.4	(4.3-4.6)	82.1	(72.6-91.3)
TAN	g/kg	4.2	(4.0-4.3)	38.2	(32.9-41.7)
Phosphorus	g/kg	0.03	(0.01-0.04)	0.16	(0.14-0.19)
Potassium	g/l	6.6	(6.4-6.8)	42.7	(40.7-46.5)
Sodium	g/l	0.8	(0.8-0.8)	4.2	(3.9-4.5)
Chlorine	g/l	2.8	(2.6-2.9)	14.2	(13.6-15.0)
Sulphate	g/l	1.7	(1.4-2.1)	6.8	(6.2-7.0)
Total solids	g/kg	21.8	(21.1-22.4)	348	(325-371)
Ash	g/kg	14.4	(14.1-14.6)	86.7	(72.8-98.5)
Suspended solids	g/kg	0.6	(0.3-1.1)	6.4	(3.7-12.2)
pH		8.8	(8.6-9.0)	4.1	(3.9-4.3)
Elec . Conductivity	mS/cm	41.2	(40.3-41.5)	243	(233-251)
Density	g/ml	not measured		1.2	(1.2-1.2)

(*) As this urine was collected from a convex conveyor belt that also carried the feces, it was slightly contaminated with feces.

CONCLUSION

It proved possible to evaporate water from concentrated acidified pig urine and scrub ammonia from air simultaneously. These functions were combined in a scrubber using animal heat in exhaust ventilation air as energy source for evaporation. The average evaporation rate is therefore highly affected by the humidity of the inlet air. This humidity is a result of the psychrometric conditions in the pig house, as influenced by the climate, ventilation set points, and by the diet of the pigs.

The measured evaporation in the scrubber was 1.21 g of water per m^3 of exhaust ventilation air at average air inlet conditions of 74% relative humidity and 19 ^oC. The maximum adiabatic evaporation at these conditions is 1.45 g/m^3 , assuming complete saturation of the air. Under the observed conditions, the volume reduction of pig urine could only be 70%. The concentration factor can be higher if the humidity of the inlet air of the scrubber is lower.

The efficiency of ammonia scrubbing with the concentrated pig urine fraction at pH 4 varied from 68 to 95%. The total salt concentration in the liquid seemed to be an important factor in the ammonia removal efficiency.

The concentration of acidified pig urine in an scrubber yields a liquid containing almost 10% nitrogen and 5% potassium by weight. The phosphorus content was below 0.2%. This concentrate is a brown liquid with a characteristic odor that is less pungent than the odor of pig slurry. The concentrate has a conductivity of 250 mS/cm and a density of 1.2 kg/l. In a field experiment the concentrate proved a suitable N/K fertilizer on a potato crop.

Acknowledgements

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