



Ozone treatment of slurry from finishers in climate chambers

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Abstract

A trial was conducted in two climate chambers at Danish Pig Production's experimental station Grønhøj. The two climate chambers were identical except for the fact that the company Bio-Aqua A/S was responsible for treating the slurry under the slatted floor in one of the chambers.

Each of the climate chambers comprised two traditional finisher pens with 16 pigs in each pen, and the trial was conducted twice with finishers weighing 30-110 kg.

The slurry treatment was started a few weeks after the finishers had been placed in the climate chambers. Once a week, the slurry was flushed into a tank located outside the building. The slurry was then pumped into a container where it was treated with ozone. During the treatment, the slurry was fractionated, and the thin, relatively clear fraction was returned to the slurry pits in the climate chambers, while the solid fraction was transferred to the manure storage area.

The odour emission from the two climate chambers with and without treated slurry was measured the day after the slurry had been in one of the chambers. The odour emission was statistically significantly lower from the climate chamber where the slurry had been treated with ozone. The odour emission was 490 OU_E/sec. per 1000 kg pig from the control chamber and 240 OU_E/sec. per 1000 kg pig from the chamber with the treated slurry.

On-line measurements of the ammonia concentration were performed using equipment from Veng System A/S, and the ventilation rate was measured using Fancom measurement wings throughout the entire production cycle. Based on the on-line data registrations, it could be concluded that the treatment strategy did not result in increased ammonia emissions from the section with treated slurry. It had been expected that the ammonia emissions could increase since ozone treatment results in a higher pH level and, consequently, in increased ammonia emissions. However, only the thin fraction with the lower nitrogen content was returned to the slurry pits, and therefore the higher pH did not result in increased ammonia emissions from the climate chamber.

There was a significant reduction in the emission of hydrogen sulphide from the chamber where the slurry had been treated with ozone compared with the control chamber, and the emission of practically every chemical compound measured by GC/MS and MIMS was reduced as a result of the treatment.

For one batch of pigs, 7 treatments were performed, resulting in an electricity consumption of 7.75 kWh/pig. With an electricity price of DKK 0.75 per kWh, this will result in an energy cost of DKK 5.80 per pig. Future trials will demonstrate the optimum number of treatments.

Furthermore, trials are currently being conducted in climate chambers where both ozone and a polymer are added. Infarm A/S has started to upgrade the pilot slurry treatment system so that it can be used on a commercial scale. The new system is called smellFIGHTER and will be tested by Danish Pig Production in the summer of 2008.

Background

Odour from a pig production unit primarily originates from the manure, and developing a new method to make the slurry relatively odourless would be of great relevance to a number of pig producers [1].

The company Bio-Aqua A/S normally works with waste water purification for industrial companies. In 2006, the company collaborated with Danish Pig Production on a number of laboratory trials at the experimental station Grønhøj in which slurry was treated with varying amounts of ozone and treatment times.

One of the main results from the preliminary investigations was that the slurry was fractionated during the ozone treatment. The slurry was separated into:

- A solid fraction
- A thin clear fraction
- A foam fraction

The result from the separation of slurry using ozone had not previously been seen. No Danish or international articles mention that ozone treatment of slurry results in fractionation. When the slurry was treated with ozone, the pH in the slurry increased, resulting in increased ammonia emissions. The international literature also states that ozone treatment of slurry results in a pH increase [2], [3].

In collaboration with Research Centre Bygholm, the Faculty of Agricultural Sciences and Force Technology A/S, a pre-study was conducted in which head-space measurements were taken over slurry stored in closed containers. The slurry had been treated with ozone using different treatment strategies. The results from the laboratory measurements indicated that the odour from the thin clear fraction could be reduced by more than 95 per cent.

On the basis of the positive lab results, an innovation project was initiated with financial support from the Innovation Act, The Directorate for Food, Fisheries and Agri Business in Denmark. The main purpose was to study whether it was possible to use the positive lab tests in a pig facility by recording odour emission and a series of chemical compounds from two climate chambers for finishers with and without treating the slurry with ozone, respectively. Furthermore, the aim was to study whether the ammonia emission increased from the chamber in which the slurry was treated with ozone.

Materials and methods

The study was conducted in two climate chambers at Danish Pig Production's experimental station Grønhøj. The two climate chambers were identical except for the fact that Bio-Aqua treated the slurry with ozone in one of the chambers.

Climate chambers

Each climate chamber consisted of two traditional finisher pens with 16 pigs per pen. Each pen had a simple dry feeder and a nipple drinker. The floor consisted of 1/3 drained floor and 2/3 concrete slats. There

was an approx. 40 cm deep slurry pit under each pen. A sprinkling system with one nozzle was installed above the dunging area in each pen to cool the pigs when outdoor temperatures reached 15°C.

Figure 1 shows a photo of a pen in the climate lab and a photo taken outside the individual climate chambers showing the measurement equipment. Appendix 1 provides details on housing dimensions.



Figure 1. Climate chambers and measurement equipment at experimental station Grønhøj (photo: Merete Lyngbye).

Ozone treatment systems

A container containing the equipment for treatment of the slurry was placed outside the pig facility.

The slurry treatment was initiated a few weeks after the pigs had been transferred to the chambers. Once a week, the slurry was pumped into a tank located outside the building. The slurry was subsequently pumped into a container where it was treated with ozone in two steps. In step 1, ozone was quickly dissolved into the slurry, which subsequently fractionated into a thin fraction and a thick precipitated fraction. Subsequently, the thin fraction was once again treated with ozone. During this treatment, a foam layer formed on the top of the slurry in the treatment tank. A scraper was installed that pushed the foam into a tank. The thick precipitated fraction was also transferred into the tank. The thin, relatively clear fraction was pumped into a silo located outside the container and then flushed back into the pig facility. Treatment of the slurry from the two pens lasted approx. 3 hours a time. The treatment was not automatic in this trial.

The company Infarm A/S supplied a screw press from Swea so that a pre-separation of the slurry could be performed. The screw press was used in connection with two treatments and was then disconnected, because some of the chemical substances might have been transferred to the thin fraction, which was returned to the finishing unit.

Figure 2 shows a photo of the container outside the facility, and Appendix 2 shows photos taken inside the container.



Figure 2. Container containing equipment to treat the slurry with ozone (photo: Merete Lyngbye).

Production and feeding

Two batches of pigs were included in the trial to determine the level of odour reduction that could be achieved when treating the slurry with ozone.

Sixteen pigs were placed in each pen at the start of each batch, i.e. each climate chamber housed 32 pigs. One of the two pens housed castrates and the other female pigs.

In batch 1, the pigs weighed 35 kg when placed in the pens and 117 kg at delivery for slaughter, and in batch 2, they weighed 29 kg when placed in the pens and 110 kg at delivery for slaughter. The high end weight, particularly in batch 1, was due to the fact that the pigs were kept slightly longer to conduct an additional study in which slurry was replaced with water in the section with ozone-treated slurry.

The feed was based on wheat, barley and soybean meal and was heat-treated (81°C) and pelleted. The composition of the feed is shown in Appendix 4.

The pigs were fed ad libitum. The feed boxes were filled every morning and the amount of feed was weighed.

Odour

Odour was measured the day after the slurry had been treated with ozone. Odour measurements were taken on 11 days in batches 1 and 2. On each measurement day, two air samples were collected from each climate chamber between 11:00 a.m. and 1:30 p.m.

The odour samples were collected in the exhaust unit where a Teflon™ tube was installed and connected to a 30 litre Tedlar® bag. The Tedlar® bag was placed in a tight, closed box on which an SKC pump was installed. The SKC pump created a vacuum in the box, and at the same time the Tedlar® bag was filled with air from the exhaust unit. All the equipment was placed outside the pig facility to avoid disturbing the pigs during collection of the odour samples. The samples were collected according to the European CEN standard [4]. The bags filled at a rate of 0.8 litres per minute, i.e. the bags were filled over a period of approx. 35 minutes. The samples were subsequently mailed to the Danish Meat Research Institute, where the odour concentration of the samples was analysed the following day. The analysis was performed in accordance with the European CEN standard [4].

Hydrogen sulphide

Immediately after air samples had been collected for olfactometric analysis, the hydrogen sulphide concentration was measured in the ventilation exhaust. The hydrogen sulphide concentration was measured using Jerome 631-XE. According to the producer, this instrument is affected by thiols and dimethyl sulphide, but this does not seem to have had a significant impact on the overall results. Six consecutive recordings were made in each ventilation exhaust.

GC-MS and MIMS for determination of chemical compounds

When air samples were collected for olfactometric analysis, samples were also collected on six days of measurement for analysis of chemical compounds. The samples were collected in pipes containing absorbent materials, Tenax TA and Carbograph 5 TD, which are small particles to which chemical compounds bind when the housing air is blown through the pipe. A pump was adjusted to provide a flow through the pipe of 100 ml a minute.

The pipes were subsequently forwarded for analysis of content of chemical compounds with gas chromatography - mass spectrometry detection (GC-MS). A detailed description of the method can be found in [9].

Lugttek A/S performed the analyses in batch 1, and the Technological Institute performed the analyses in batch 2.

The Technological Institute also used Membrane Inlet Mass Spectrometry (MIMS) for continuous measurements. This method is described in detail in [5]. With the MIMS equipment, online measurements of chemical compounds can be taken, and measurements were taken in the ventilation exhaust in two periods in batch 2.

The compounds measured by GC-MS and MIMS are shown in Appendix 5.

Ammonia and carbon dioxide

The concentrations of ammonia and carbon dioxide were measured in the air intake and the outlet air using a VE 18 multi sensor from Veng System A/S. This equipment consisted of pumps that pumped, via teflon tubes, approx. two litres of air per minute from the air intake and exhaust to the equipment that analysed the content of ammonia and carbon dioxide in the air. Polytron 1 from Dräger with a measurement area of 0-50 ppm was used for the ammonia measurements, and a Vaisala with a measurement area of 0-5,000 ppm was used for the carbon dioxide measurement.

A manifold placed immediately before the ammonia and carbon dioxide equipment ensured that air was submitted for analysis on an alternating basis. Alternation took place every ten minutes, and the last value recorded was the one stored.

During every second measurement period, outdoor air was led through the ammonia and carbon dioxide measurement equipment. The air was preheated to 34°C before it was pumped into the measurement equipment. The outdoor air was led through the measurement instruments every other time, and the air was preheated before it was pumped into the measurement instruments, to ensure that the ammonia sensor operated in a stable manner.

Previous experiences have shown that the calibration has not always been maintained correctly, particularly during periods of high relative humidity in the air. The preheating was carried out by placing the manifold in a steel box that could be heated electrically.

Controlled measurements of the ammonia concentration were performed using Kitagawa detection tubes in the morning on weekdays.

Temperatures and air flows

The outdoor temperature and the housing temperature were measured using a VE 10 temperature sensor from Veng System A/S. In each section, the ventilation air flow was measured using a Fancom measuring wing. The outdoor temperature and housing temperature and ventilation air flow were collected electronically. Furthermore, the temperature and the relative humidity were recorded using the multimeter TSI VelociCalc 8347 during the collection of the odour samples.

Electronic equipment for data collection

A BUS system was established, and the following devices were connected to the system: VE18 multi sensor, VE18 temperature sensors, ventilation measurement wing from Fancom and a computer. Software from Veng System A/S was installed on the computer that, among other things, controlled that data were stored every other hour.

Composition of slurry

When the slurry pit in the control facility was full, slurry was pumped out. Immediately before slurry was pumped out, a slurry sample was collected from each pen in both chambers under the lying area and under the dunging area. The samples were collected by lowering a pipe with a diameter of 1.5 cm and pouring the content into a glass. The slurry samples were frozen, and, when a batch of pigs was finished, all slurry samples were forwarded for analysis at Eurofins where they were analysed for content of total nitrogen, ammonium nitrogen, phosphorus, potassium, dry matter, sulphur and pH.

Energy consumption for treatment of slurry

An energy measurement device recorded the energy consumption used in the container. In batch 2 before and after weekly treatment of slurry, the energy consumption was recorded manually.

Calculations and statistics

The odour emission per 1,000 kg animal was calculated on the basis of the measured odour concentration, ventilation air flow and average pig weight and the number of pigs in the facility using the equation below:

$$\text{OU}_E/\text{sec. per 1000 kg} \quad \frac{L \times Q \times 1,000}{W \times N \times 3,600} \quad \text{pig} =$$

L: Odour concentration, OU_E/m^3
Q: Ventilation air flow, m^3/hour
W: Av. weight/pig, kg
N: Number of pigs in the section

The measured odour concentrations are logarithmically distributed, and odour data were therefore logarithmically transformed before they were entered into the statistical analysis. The logarithmically transformed odour concentrations and odour emissions in the two climate chambers with and without treated slurry were subjected to an analysis of variance with the procedure MIXED in SAS taking into consideration repeated measurements per day. The statistical model included group and batch as class variables, while the date of the collection of samples was included as a random variable.

A previous study found a linear correlation between the handheld ammonia measurements made daily with Kitagawa detection pipes and the ammonia concentrations collected electronically using Veng equipment [6]. Kitagawa pipes were determined to be the correct values. For each batch, the calibration line between the daily Kitagawa recordings and the Veng recordings was determined. The calibration line was used to correct the data collected electronically using Veng equipment. Subsequently, the ammonia emission was calculated on the basis of the ammonia concentration, ventilation air flow and the number of pigs in the facility using the following equation:

$$\text{G NH}_3\text{-N}/\text{hour per pig} \quad \frac{M \times V \times Q \times P}{R \times T \times N \times 1,000} =$$

M: Molecular mass of N, 14 g/mol
V: Concentration, ppm = ml/m^3
Q: Ventilation output, m^3/hour
P: Pressure, 1 atm.
R: Gas constant, 0.0821 litre x atm/mol x Kelvin
T: Temperature in Kelvin, 298 K
N: Number of pigs in the section

Ammonia concentrations and ammonia emissions and pH recordings in the two climate chambers with and without treated slurry were subjected to an analysis of variance with the procedure MIXED in SAS.

For the measured chemical compounds in the ventilation exhaust, the percentage reduction was calculated. Some of the chemical compounds were only identified in some of the samples, and, if the content of

a chemical compound in the ventilation exhaust was below the detection limit, the concentration in the further calculations was determined to be equal to the detection limit. The detection limit for the individual compounds is shown in Appendix 5.

Results and discussion

The slurry treatment system was installed and implemented between November 2006 and February 2007. Emissions were measured in two batches, one from March 5 to May 22, 2007, and one from June 7 to August 30, 2007. The production results are shown in Appendix 3. The exact dates for treatment of slurry are shown in Appendix 2.

Odour

Table 1 shows the odour concentrations and odour emissions for the two batches of pigs individually and together. Furthermore, Figure 3 shows a graph of the recorded odour emissions.

Table 1. Odour concentration and odour emission. The measured values must be compared within each batch. The 95% confidence interval is stated in brackets.

Block	Group	Measurements	Odour concentration (OU _E /m ³)	Odour emission (OU _E /sec./1,000 kg)
1	Control	8	3,040 (1,997-4,638)	480 (343-658)
	Treated slurry	8	1,350 (981-1,869)**	230 (174-309)
2	Control	12	2,200 (1,512-3,202)	490 (377-638)
	Treated slurry	12	980 (750-1,277)**	240 (192-298)
1+2	Control	20	2,480 (1,697-3,622)	490 (385-614)
	Treated slurry	20	1,110 (881-1,402)**	240 (196-286)***

* : P<0.05 ; ** : P<0.01 ; *** : P<0.001

A significantly lower odour emission was measured from the climate chamber in which the slurry was treated with ozone. The odour emission was 490 OU_E/sec. per 1,000 kg animal from the control chamber and 240 OU_E/sec. per 1,000 kg animal from the climate chamber with treated slurry.

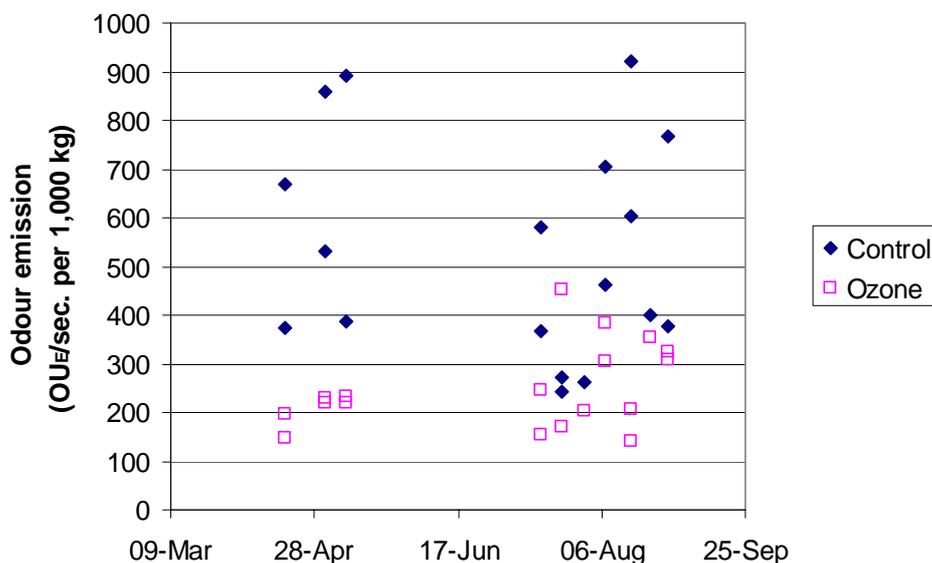


Figure 3. Odour emission from two climate chambers with and without ozone treatment of slurry, respectively.

Ammonia

Table 2 shows the ammonia concentrations and the ammonia emissions from the two climate chambers and all the other data recorded electronically using equipment from Veng System A/S.

Housing temperature and content of carbon dioxide were both at the same level within each batch. In batch 2, the ventilation output was slightly higher from the chamber with treated slurry. However, the carbon dioxide concentrations were identical in the two chambers, which means that the small difference in ventilation output will be insignificant when comparing ammonia emissions from the two climate chambers.

In Figure 4, the 24-hour average of the ammonia emission for batches 1 and 2 from the two climate chambers is graphically illustrated.

Table 2. Temperature, ventilation air flow, carbon dioxide concentration, ammonia concentration and ammonia emission in the two climate chambers with and without treated slurry. The measured values must be compared within the individual batch. The standard deviation is stated in brackets.

Batch	Group	Measurement days	Outdoor temp. (°C)	Housing temp. (°C)	Ventilation per pig (m ³ /hour)	CO ₂ (ppm)	NH ₃ (ppm)	Ammonia emission (g NH ₃ -N / hour)
1	Control	73	8.2	18 (1.6)	61 (24)	1,680 (368)	16 (3.1)	0.52
	Treated slurry	73		18 (1.7)	60 (23)	1,650 (244)	8 (1.4)	0.26***
2	Control	78	14.9	20 (1.7)	72 (15)	1,140 (164)	7 (3.3)	0.27
	Treated slurry	78		20 (2.0)	79 (14)***	1,150 (166)	5 (1.7)	0.20
1+2	Control	151	15.4	19.7 (2.5)	68 (18)	1,320 (356)	10 (5.3)	0.35
	Treated slurry	151		20.2 (2.8)	73 (18)	1,320 (305)	6 (2.2)	0.22

* : P<0.05 ; ** : P<0.01 ; *** : P<0.001

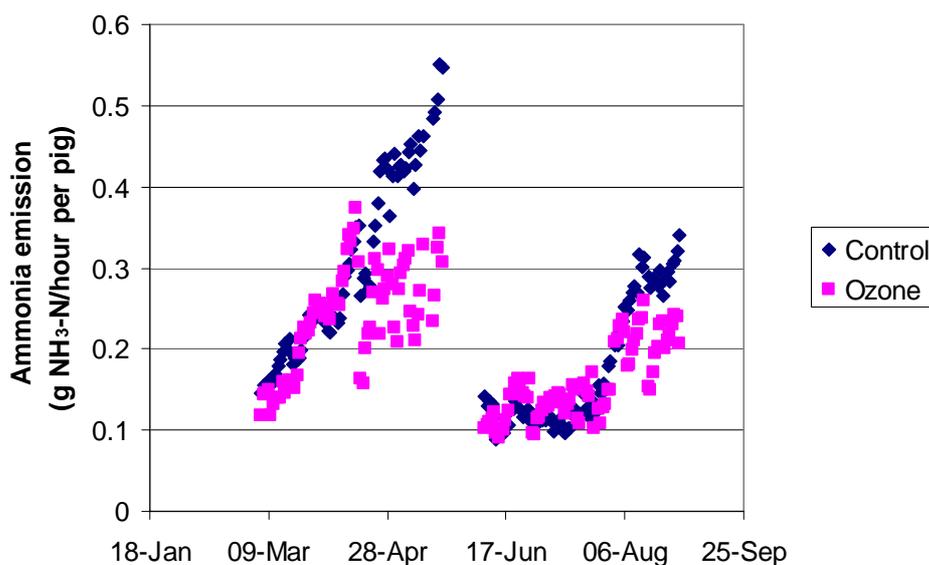


Figure 4. 24-hour average of ammonia emission measured every second hour from two climate chambers with and without treatment of slurry with ozone.

On the basis of data from batch 1, a significant reduction in ammonia emission was calculated from the climate chamber with ozone-treated slurry. The weekly treatment of slurry with ozone started on April 18, and, as can be seen in Figure 4, it is clear that from this day the emissions from the two climate chambers differ from each other.

When including data from the whole of batch 2, there was no statistically significant difference between the ammonia emissions from the chambers for batch 2. For the treatments performed on July 20 and July 30, the slurry was pre-separated with a screw press from Swea before being treated with ozone. From August 6, the screw press from Swea was disconnected, and the slurry was only treated with ozone. When including data after August 6, when the screw press was disconnected, there was also a statistically significant reduction in the ammonia emission for batch 2. The screw press was disconnected because some of the chemical substances might have been transferred to the thin fraction, which was returned to the climate chamber.

Due to the batch effect, this study cannot document that an ammonia reduction in the ventilation exhaust can be obtained from treating slurry with ozone for the two batches of pigs. However, it can be concluded that the treatment strategy does not increase ammonia emissions from the pig facility.

An increased ammonia emission had been expected because the ozone treatment results in a higher pH level in the slurry. However, since it is only the thin fraction that is returned to the climate chamber, and, as this fraction has a lower nitrogen content, as seen in Table 4, the higher pH level did not result in a higher ammonia emission from the ventilation outlet.

Hydrogen sulphide

Table 3 shows the average concentrations and emissions of hydrogen sulphide for batches 1 and 2. Figure 5 shows the emissions on individual days. In the climate chamber where the slurry was treated with ozone, the concentration and emission of hydrogen sulphide were significantly reduced.

Table 3. Concentration and emission of hydrogen sulphide. The standard deviation is stated in brackets.

Batch	Group	Measurements	Concentration of hydrogen sulphide (ppm)	Emission of hydrogen sulphide (µg/hour/pig)
1+2	Control	10	0.15 (0.10)	3.71 (2.25)
	Treated slurry	10	0.03 (0.04)**	0.66 (0.87)***

* : P<0.05 ; ** : P<0.01 ; *** : P<0.001

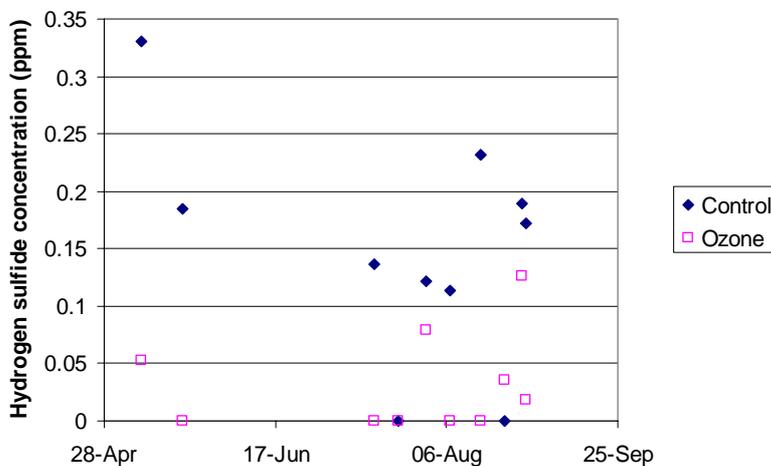


Figure 5. Concentration of hydrogen sulphide in two climate chambers with and without treatment of slurry with ozone.

For batch 2, the hydrogen sulphide concentration was 0 ppm in the control chamber on two days of measurement; July 23 and August 23. In this batch, slurry was flushed out twice, on July 18 and August 20, and the two days with low concentrations of hydrogen sulphide were the first two days of measurements of odour and hydrogen sulphide after the slurry had been flushed out.

The level in the control chamber corresponded to the level recorded in two batches of finishers in a study of benzoic acid for finishers [8]. In that study, the average of 26 samples for two batches was 206 and 157 ppb in the control section.

To put the measured concentrations of hydrogen sulphide into perspective, they were compared with the marginal value of the National Working Environment Authority and the odour threshold. The marginal value of the Authority for hydrogen sulphide is 10 ppm [7], which means that the recorded hydrogen sulphide concentrations are far below the working hygienic marginal value.

The odour threshold for hydrogen sulphide varies in the literature. A database made by the National Research Centre for the Working Environment lists the following examples of odour thresholds: 0.76 $\mu\text{g}/\text{m}^3$ recorded by Woodfield; 11.5 $\mu\text{g}/\text{m}^3$ recorded by Amore; 25.7 $\mu\text{g}/\text{m}^3$ recorded by Devos et al. Stated in ppb, these thresholds lie in the interval 0.5-18 ppb. In comparison, the hydrogen sulphide concentration in the control facility averaged 150 ppb. If the hydrogen sulphide concentration is 150 ppb, the air must be diluted 8-300 times before it is no longer possible to smell the hydrogen sulphide. In the climate chamber with treated slurry, the average hydrogen sulphide concentration in the facility with treated slurry measured 30 ppb, and if air containing hydrogen sulphide in a concentration of 30 ppb is to be diluted to below the odour threshold for hydrogen sulphide, it needs to be diluted 2-60 times. The odour concentration in the control chamber averaged 2,480 OU_E/m^3 , and if this odour concentration is detected at a given time, the air needs to be diluted 2,480 times before the neighbours will be unable to smell it. Seen in this perspective, hydrogen sulphide is not very important for the odour around a pig facility.

Chemical compounds measured by GC-MS and MIMS

The percentage reduction of emissions of chemical compounds, calculated as the amount of compound per time unit ($\mu\text{g}/\text{hour}$), is determined on the basis of the results of the GC-MS analyses and the recorded ventilation air flow. Figures 6 and 7 show the most important groups of odorants. In the figures, a reduction larger than 0 denotes that the emission from the treatment chamber is lower than the emission from the control chamber.

As seen in the two figures, a reduced emission is generally recorded for the most important odorants as a consequence of the ozone treatment. In batch 1, the sulphur compounds are reduced between -25 and +80%. The volatile organic acids are reduced by up to 65%, though in some cases reductions of -35% were seen. The phenols are reduced by 10-85%. In batch 2, the sulphur compounds are reduced by up to 75%, but, for reasons unknown, one day deviates with an increased emission due to treatment. The reduction in the emission of organic acids is larger for batch 2 than for batch 1 with reductions of up to 90% for propane acid, but also with increased emissions on some days. With the exception of one measurement, a 30-90% reduction in phenols is seen. For both indole and skatole, the results for both batches are more varied, but the measured values are low and even small variations will therefore affect the relative reduction.

A number of degradation products from the primary odorants were detected in both chambers. These were in particular oxidized aliphatic hydrocarbons such as ketones, aldehydes and alcohols. However, the content of these compounds in the exhausted air was so low that in several samples they did not exceed the

limit of detection for the method, and a discussion of the results can not be given. As seen in Appendix 5, there were differences in the number of compounds that the two laboratories analysed for.

Ozone, Grønhøj, April-May 2007

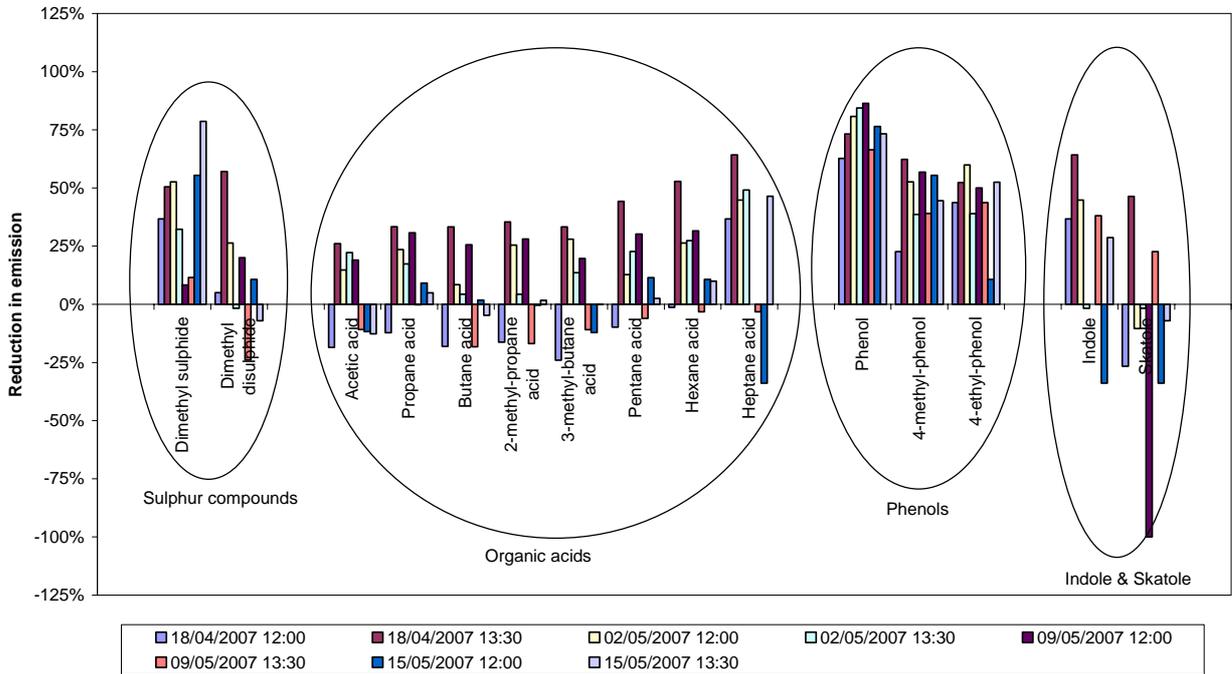


Figure 6. Reduction of chemical compounds during ozone treatment of slurry for batch 1 measured by GC-MS. Negative reductions denote an increase of chemical compounds during treatment.

Ozone, Grønhøj, July-August 2007

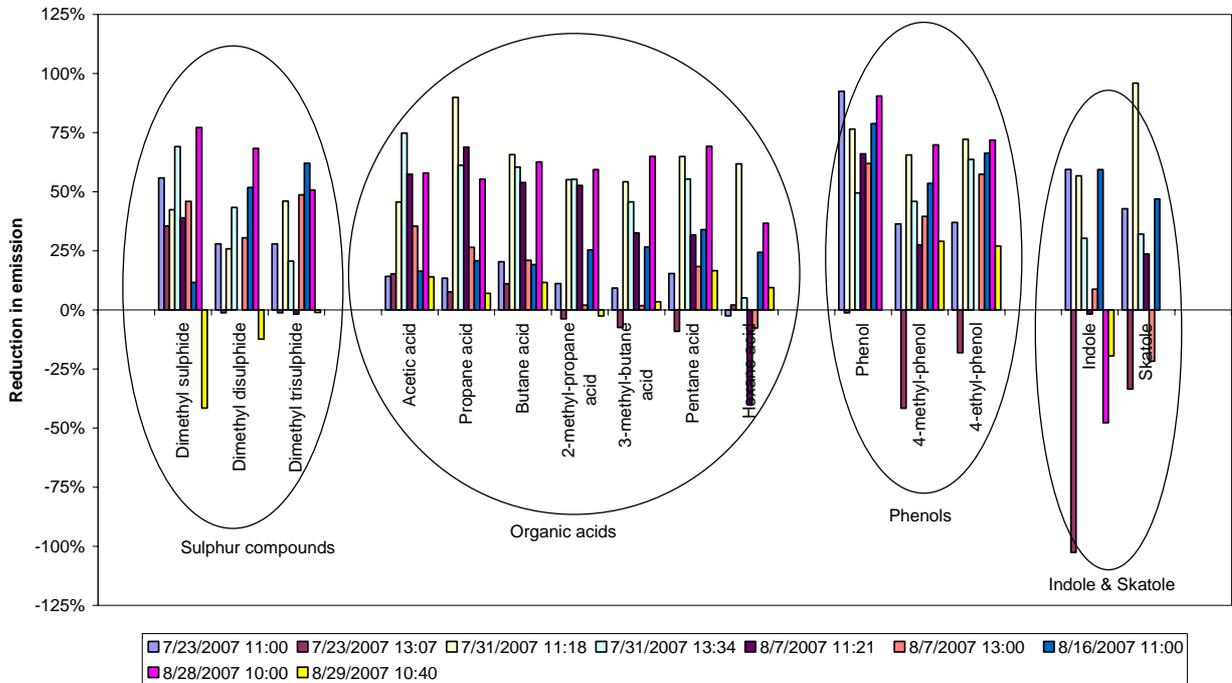


Figure 7. Reduction of chemical compounds during ozone treatment of slurry for batch 2 measured by GC-MS. Negative reductions denote an increase of chemical compounds during treatment.

In Figure 8, MIMS data are shown as a percentage reduction of the concentration in the exhausted air. “ROS” is an abbreviation for “Reduced Organic Sulphur compounds”. Due to technological reasons, it is not possible to measure the individual chemical compounds, but only compound groups. As with the GC-MS measurements, a general reduction in the primary odorants is seen, particularly for phenols (0-60%) and organic acids (30-95%). The sulphur compounds also show a clear tendency to reduction, but one measurement deviates for unknown reasons. For indole and skatole, the pattern is more complicated, similar to the GC-MS measurements.

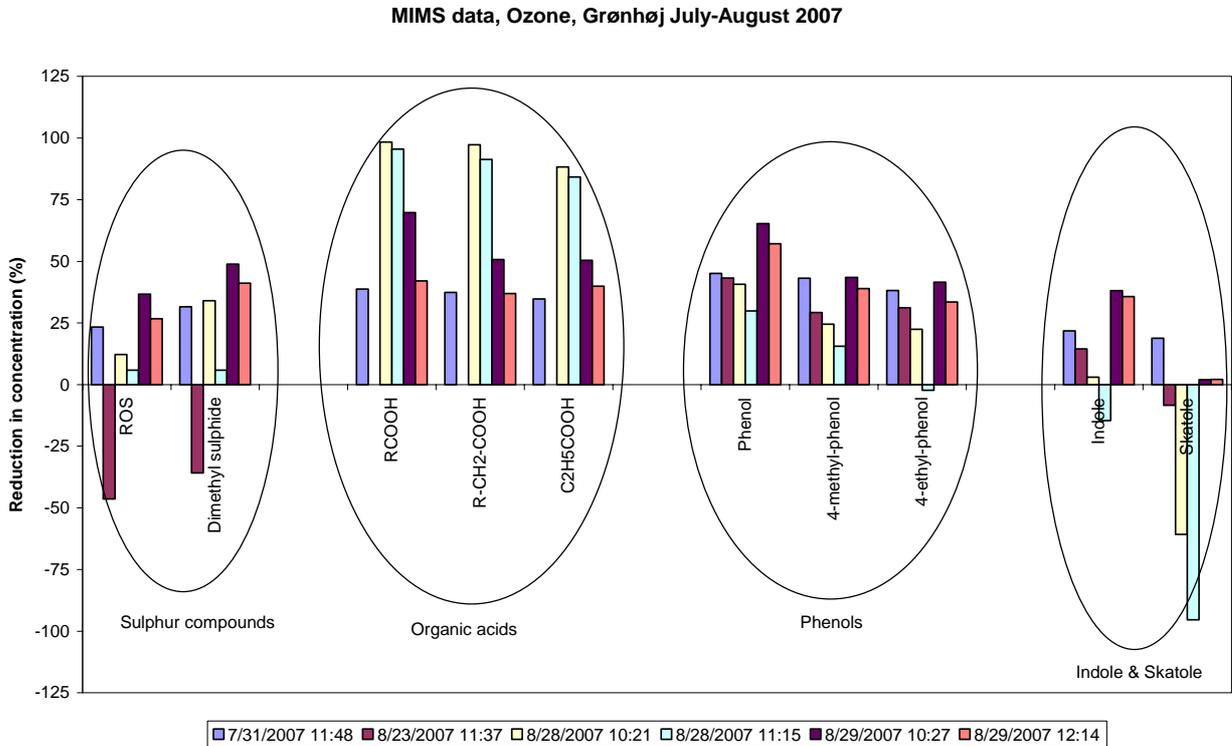


Figure 8. Reduction in the concentration of chemical compound groups for batch 2 during ozone treatment measured by MIMS. Negative reductions denote an increase of chemical compounds during treatment.

Composition of slurry

In batch 1, slurry was flushed out twice from the control facility: once halfway through the production cycle and once immediately after the pigs had been picked up for slaughter. In batch 2, it was necessary to flush out the slurry one more time, as the slurry pit in the facility was full ten days before the pigs were picked up for slaughter. However, results from the last flush are not included in the calculations. It was necessary to flush one more time in batch 2 because of the increased amount of water used for sprinkling. During outdoor temperatures below 15°C, the sprinkling system is not used at all, while during the summer with temperatures above 20°C sprinkling takes place every half hour for 1.5 minutes. The results are shown in Table 4.

The content of nitrogen, ammonium, phosphorus and potassium was significantly lower in the slurry from the chamber with treated slurry. This is due to the fact that during treatment, the slurry was separated from dry matter. The content of sulphur was not significantly different between the control and the treated slurry.

During ozone treatment of the slurry, an increase in pH was expected. However, when slurry was flushed out from the control section, there were no differences in pH in the slurry in the two climate chambers.

Table 4. Composition of the slurry in the climate chamber with traditional finisher slurry and in the climate chamber with treated slurry. The treated slurry consists of the thin clear fraction that was returned to the climate chamber. The 95% confidence interval is stated in brackets.

Batch		Total nitrogen	Ammonium nitrogen	Phosphorus	Potassium	Sulphur	Dry matter	pH
	Group	Kg/t	Kg/t	Kg/t	Kg/t	Kg/t	%	
1	Control	7.5 (5.9-9.0)	5.1 (4.2-6.1)	2.4 (1.6-3.1)	3.7 (3.0-4.5)	0.4 (0.1-0.7)	10.4 (7.3-13.6)	7.2 (7.0-7.5)
	Treatment	3.8 (2.3-5.4)	2.7 (1.7-3.7)	1.3 (0.6-2.1)	1.9 (1.1-2.7)	0.3 (0.1-0.6)	5.8 (2.6-8.9)	7.5 (7.2-7.7)
2	Control	5.7 (4.1-7.2)	3.5 (2.5-4.5)	1.9 (1.1-2.6)	2.2 (1.5-3.0)	0.4 (0.2-0.7)	8.2 (5.0-11.3)	6.7 (6.4-6.9)
	Treatment	2.0 (0.5-3.6)	1.1 (0.1-2.0)	0.8 (0.1-1.6)	0.4 (-0.4-1.2)	0.4 (0.1-0.6)	3.5 (0.3-6.7)	6.9 (6.7-7.1)
1+2	Control	6.6 (5.3-7.8)	4.3 (3.5-5.1)	2.2 (1.5-2.7)	3.0 (2.4-3.6)	0.4 (0.2-0.6)	9.3 (6.7-11.9)	6.9 (6.8-7.1)
	Treatment	2.9*** (1.7-4.2)	1.9*** (1.1-2.7)	1.1* (0.5-1.7)	1.1*** (0.5-1.8)	0.4 (0.1-0.6)	4.6* (2.0-7.2)	7.2 (7.0-7.4)

* : P<0.05 ; ** : P<0.01 ; *** : P<0.001

The separated dry matter was not subjected to systematic slurry analyses. However, in a current trial in the climate lab, ozone is being tested together with a polymer, and here slurry samples are collected in the container in connection with the treatment. When that trial is finished, we will have more specific knowledge about the separated dry matter and the thin clear fraction that is returned to the climate chamber.

Energy consumption

In batch 2, odour measurements were taken in connection with 7 treatments of slurry, and the energy meter that recorded the energy used in the container was read before and after each treatment. In connection with the 7 treatments, 7.75 kWh per pig was used. With an electricity price of DKK 0.75/kWh, this results in an energy cost of DKK 5.8 per pig. Future studies will demonstrate whether 7 treatments per batch are sufficient.

Trials are currently being conducted in climate chambers, where, besides ozone, a polymer is also added. Infarm A/S is developing the system so it can be used on a commercial scale. The system, which is called Smell Fighter, will be tested by Danish Pig Production in the summer of 2008.

Conclusion

Measurements taken in a pilot system for treatment of slurry have shown that it is possible to use ozone to reduce odour from pig production units.

The odour emissions from two climate chambers with and without treated slurry were measured the day after the slurry had been treated in one chamber. A significantly lower odour emission was measured from the chamber where the slurry was treated with ozone. The odour emission was 490 OU_E/sec. per 1,000 kg animal from the control chamber and 240 OU_E/sec. per 1,000 kg animal from the climate chamber with treated slurry.

Furthermore, it can be concluded that the treatment strategy does not increase the ammonia emissions from the section with pigs.

The hydrogen sulphide emission from the climate chamber was reduced significantly when the slurry was treated with ozone, and the emissions of almost all chemical compounds detected by GC-MS and MIMS were reduced.

7.75 kWh/pig were used during 7 treatments of slurry in one batch of pigs. With an electricity price of DKK 0.75/kWh, this results in an energy cost of DKK 5.8 per pig. Future studies will demonstrate whether 7 treatments per batch are sufficient.

Further studies are currently being conducted in the climate chambers where, besides ozone, a polymer is also added, and the company InfarmA/S is further developing the system so it can be used on a commercial scale. The system, which is called Smell FIGHTER, will be tested by Danish Pig Production in the summer of 2008.

References

- [1] Lyngbye, M og Riis, A.L.: (2005): Grisenes indflydelse på lugtemissionen. Erfaring nr. 0503, Landsudvalget for Svin.
- [2] WU, J.J.; Park, S.; Hengemuehle S.M., Yokoyama, M.T.; Person, H.L., and Masten S.J.: (1997): The Effect of Storage and Ozonation on the Physical, Chemical, and Biological Characteristics. Supplied by British Library – "The world's knowledge".
- [3] Wu, J.J; Park, S.; Hengemuehle S.M., Yokoyama, M.T.; Person H.L., and Gerrish J.B, Masten S.J.: (1999): The Use of Ozone to reduce the Concentration of Malodorous Metabolites in Swine Manure Slurry. J. Agric. Engng Res, 72, pp. 317-327.
- [4] Dansk Standard: (2003): Luftundersøgelse - Bestemmelse af lugtkoncentration ved brug af dynamisk olfaktometri. DS/EN 13725:2003.
- [5] Feilberg, A.; Schäfer, A. og Lyngbye, M.: (2006): Udvikling af måleteknik for optimering og beskrivelse af lugtbe-grænsende teknologier til husdyrbrug. Arbejdsrapport fra Miljøstyrelsen nr. 22.
- [6] Lyngbye, M. og Sørensen, G.: (2005): Metode til test af fodringens indflydelse på ammoniak- og lugtemission. Meddelelse nr. 691, Dansk Svineproduktion
- [7] At-vejledning, Stoffer og materialer – C.0.1, Grænseværdier for stoffer og materialer, August 2007
- [8] Lyngbye, M og Sørensen, G: (2006): Benzoesyre i foder til slagtesvin – effekt på ammoniak og lugtemission. Meddelelse nr. 0738, Landsudvalget for Svin.
- [9] Schäfer, A og Adamsen, A.P.: (2007): Udvikling af målemetode til kemisk bestemmelse af lugtstoffer fra husdyr. Rapport fra Slagteriernes Forskningsinstitut og Lugttek A/S.

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Appendix 1

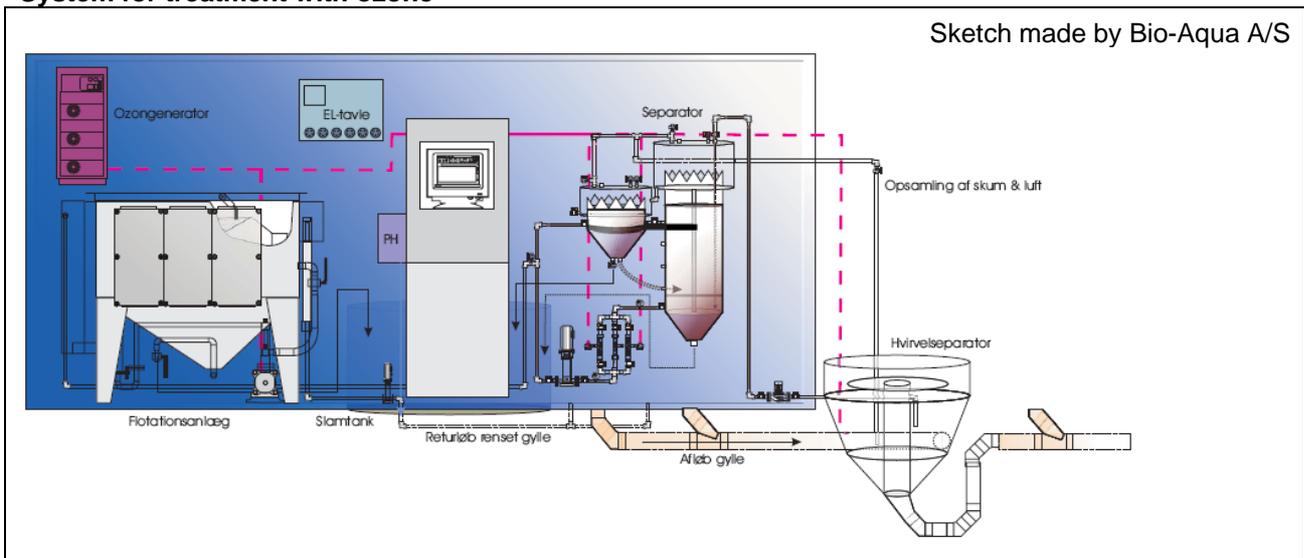
Climate laboratory

Table A1. Design of the facility

Number of climate chambers:	2
Size of each climate chamber (m):	4.86 × 4.80
Number of pens per climate chamber:	2
Number of pigs per section and per chamber:	32 pigs/section and 16 pigs/pen
Pen dimensions (m):	2.4 × 4.8
Ceiling height (m):	2.5
Floor type:	1/3 drained floor of concrete elements, slat width: 15 cm and slot width: 1.8 cm. 2/3 concrete slatted floor, slat width: 6.5 cm and slot width: 2.0 cm.
Pen sides:	Between the two pens and towards the inspection alley, the pen sides were 75 cm high. Except for the dunging area, the bottom 50 cm of the pen sides was completely closed. The backwall and the other pen side were full ceiling height.
Ventilation:	Negative pressure ventilation with diffuse air supply via the ceiling consisting of 10 cm mineral wool and Trolltex ceiling boards.
Feeding principle:	Dry feeding ad lib.
Water supply:	Nipple drinker.
Manure system:	Pull-the-chain system with a 40 cm deep pit under each pen.
Sprinkling:	One nozzle per pen with sprinkling for 20 sec. every half hour during outdoor temperatures above 15°C. During outdoor temperatures above 20°C, sprinkling is increased to 1.5 min. every half hour. To ensure that the pigs use the pen correctly in terms of dunging and lying areas, sprinkling is used independently of the outdoor temperature the first 2-14 days after pigs are transferred.
Enrichment materials:	Two wooden blocks hanging from chains. When pigs are transferred to the pen, rope is hung in all pens.

Appendix 2

System for treatment with ozone



Slurry is treated in a container placed outside.



Device for production of ozone.



A look inside the container from the door



A look into the container



Ozone is added twice. In this picture, ozone is added for the second time.



After two treatments, it was decided not to pre-separate with a SWEA screw press.

Table A2. Dates for slurry treatment

Batch 1	April 17, 2007
	May 2, 2007
	May 9, 2007
	May 15, 2007
Batch 2	June 28, 2007 (introduction of the system and no odour measurements)
	July 13, 2007
	July 20, 2007 (SWEA slurry press was used before ozone treatment)
	July 30, 2007 (SWEA slurry press was used before ozone treatment)
	August 6, 2007
	August 14, 2007
	August 22, 2007
	August 28, 2007

Appendix 3

Production results

Table A3. Production results

Batch	1 (March 5-May 22, 200)		2 (June 7-August 30, 2007)	
	Control	Treated slurry	Control	Treated slurry
Pigs penned	32	32	32	32
Pigs picked up for slaughter	27	31	31	31
Start weight, kg	34.9	35.2	29.0	28.1
Pick-up weight, kg	119	115	109	111
Slaughter weight, kg	92.2	90.2	84.3	86.9
Daily gain, g/day	1,062	1,060	966	1,026
Daily feed intake, FUgp/pig	2.93	-	2.62	2.71
Feed conversion, FUgp/kg gain	2.75	-	2.71	2.63
Av. lean meat %	59.2	59.3	59.9	59.7

- Due to recording errors, the figures for daily gain and feed conversion are not included for batch 1 with treated slurry.

Appendix 4

Feed

Table A4. Composition of ingredients, %

Wheat	37.49
Barley	37.48
Dehulled soybean meal	18.72
Molasses	1.50
Vegetable oil	1.81
Dietary chalk	1.58
Mono calcium phosphate, MCP 22.7%	0.54
Feed lime	0.44
L-lysine chloride (98%)	0.17
DL-methionine 100	0.03
L-threonine 98.5%	0.03
Vitamins and minerals	0.21

Table A5. Nutrient content

	Calculated	Analysed
FUgp, per 100 kg	109	113
Crude protein, %	17	17.4
Crude fat, %	3.9	4.1
Crude ashes, %	5.2	4.7
Lysine, g/kg	9.3	9.8
Methionine, g/kg	2.7	2.7
Cystine, g/kg	3.1	3.3
Methionine + cystine, g/kg	5.8	6.0
Threonine, g/kg	6.2	6.5
Isoleucine, g/kg	6.8	7.3
Leucine, g/kg	12.0	12.5
Histidine, g/kg	4.1	4.4
Phenylalanine, g/kg	8.1	8.2
Phenylalanine + tyrosine, g/kg	13.9	14.1
Valine, g/kg	7.9	8.5
Histidine, g/kg	4.1	4.4

Appendix 5

Chemical compounds

Table A6. Limits of detection and chemical compounds measured in the exhausted air by GC-MS and compound groups detected by MIMS.

	GC-MS	Batch 1	Batch 2	MIMS Batch 2
	Compound	Limit of detection ($\mu\text{g}/\text{m}^3$)	Limit of detection ($\mu\text{g}/\text{m}^3$)	Compound/compound groups
Sulphurous compounds				
				ROS
	Dimethyl sulphide	1	2	Dimethyl sulphide
	Dimethyl disulphide	1	2	
	Dimethyl trisulphide	1	2	
Volatile organic acids				
	Acetic acid	25	2	RCOOH
	Propane acid	25	2	C ₂ H ₅ COOH
	Butane acid	5	2	R-CH ₂ -COOH
	2-methyl-propane acid	1	2	
	3-methyl-butane acid	1	2	
	Pentane acid	5	2	
	Hexane acid	2.5	2	
	4-Methyl-pentane acid	1		
	Heptane acid	1	2	
Phenols etc.				
	Phenol	1	2	Phenol
	4-methyl-phenol (p-Cresol)	2	2	4-methyl-phenol (p-Cresol)
	4-ethyl-phenol	1	2	4-ethylphenol
	Toluen	5	2	
	3-Carene	1		
	Alpha-pinen	1		
	D-Limonen	1.5		
Aldehyde/ketones etc.				
	Benzaldehyde	1	2	
	2,3-Butanedion	1	2	2,3-butandion
	3-Hydroxy-2-butanon	2.5	2	
	Acetophenon	1		
	3-Methylbutanal	1	2	
	Hexanal	1	2	
	Heptanal	1		
	Octanal	1	2	
	Nonanal	2.5	2	
	Benzoic acid	1	2	
	Acetic acid-Butyl-ester	1	2	

Alcohols				
	1-Butanol	1		
	3-methyl-1-butanol	1		
Nitrogenous compounds				
	Indole	0.5	2	Indole
	Skatole	0.5	2	Skatole
	Trimethylamin	2.5		
	Pyridin	1		
	2,6-Dimethylpyrazin	1		
	Trimethylpyrazin	1		
	Tetramethylpyrazin	1		