Report for:
Health and Safety Executive for Northern Ireland
Health and Safety Authority, Ireland

RESEARCH INTO HYDROGEN SULPHIDE GAS (H_2S) EMISSIONS FROM STORED SLURRY WHICH HAS UNDERGONE LOW RATE AERATION

FINAL REPORT

BY

AGRI-FOOD AND BIOSCIENCES INSTITUTE (AFBI)

AND

TEAGASC GRANGE BEEF RESEARCH CENTRE

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Executive Summary

This document is the final report to the Health and Safety Executive for Northern Ireland and the Health and Safety Authority, Ireland by the Agri-Food and Biosciences Institute and Teagasc Grange Beef Research Centre.

A literature review of the emission of hydrogen sulphide gas (H_2S) from slurry, which has undergone low rate aeration is presented. This review indicates that there has been some work conducted at the laboratory scale but little research utilising full-scale systems.

Atmospheric concentrations of H_2S gas were measured during slurry deposition and storage in one livestock building between December 2005 and March 2006. The livestock building contained six under-slat slurry storage tanks, three of which were fitted with low rate aeration equipment and three, which were normally managed with no aeration. Throughout the period of housing, concentrations of H_2S were measured at slat invert level in all six tanks. The maximum concentration recorded was 7ppm, which would not be considered to pose a risk to personnel or livestock. It is concluded from this experiment that low-rate intermittent slurry aeration systems will not result in emissions of H_2S above the OELV exposure limits during animal housing periods.

Atmospheric concentrations of H_2S gas were measured at slat invert level in the centre of the tanks during mixing of non-aerated slurry and 0.5m above slat level during subsequent pumping of this slurry. Gas concentrations up to a maximum of 257ppm were recorded at slat invert level during the slurry mixing period. Variable concentrations were recorded during pumping of mixed slurry up to a maximum of 107ppm H_2S. Based on these findings it is concluded that current advice from farming organisations and health and safety authorities on safety precautions to take during slurry mixing is correct and should be followed at all times.

Concentrations of H_2S gas were recorded during pumping of slurry, which had undergone low-rate intermittent aeration during the 99 day animal housing period. Concentrations recorded at the time of pumping were generally < 10ppm with some elevated concentrations at the slat invert level immediately after commencement of pumping. Concentrations were generally lower than those recorded during pumping of non aerated and mixed slurry. In this case, mixing of slurry was not required, which reduces the risk of excessive gas exposure to personnel and livestock.

Three farms in Northern Ireland that had low rate aeration systems installed were surveyed. Atmospheric H_2S gas concentrations were measured at slat invert level over an approximate one-week period on three separate occasions for each of the three farms. It is not possible to conclude from the data presented that concentrations and durations of H_2S above slat level during low rate aeration did not pose any health risks. However, above slat level it is likely that concentrations of H_2S would be lowered by dilution with ambient air. Placement of monitors and recording interval may have resulted in some H_2S concentrations not being recorded. It is suggested that any H_2S produced above slat level during low rate aeration of cattle slurry would be below OELV limits. It is concluded that low rate aeration has potential to aid slurry management in below slat tanks without producing dangerous concentrations of H_2S within the house above slat level.

The purpose of this study was to evaluate low-rate intermittent slurry aeration systems, to assess whether their use would result in excessive hydrogen sulphide gas emissions in a typical slatted floor shed housing beef cattle. H_2S concentrations were also recorded during pumping of the aerated slurry to a reception pit remote from the slatted shed. The results were compared with those obtained when normal slurry management procedures (namely storage, mixing and pumping) were followed. It can be concluded that the use of the low-rate intermittent aeration system did not result in excessive hydrogen sulphide emissions either during the animal housing period or subsequent transfer of the aerated slurry. Indeed, since aerated slurry does not appear to require mixing prior to pumping, the risk of dangerously high concentrations being released over a short period of time is greatly reduced.

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Literature Review

Animal housing and slurry storage systems in Ireland typically comprise slatted floor livestock buildings underlain by belowground slurry storage tanks. Ventilation is an important component of livestock building design and most systems rely on natural ventilation. Whilst considered adequate in most situations, ventilation during mixing and pumping of slurry stored in the below ground tanks is usually inadequate, leading to situations where dangerously high concentrations of toxic gases can build up within the building and the immediate surroundings. One of the most dangerous gases to be released during slurry mixing is hydrogen sulphide (H_2S) gas, which is toxic and is considered to be a significant health hazard to both humans and livestock (Donham *et al*., 1982).

Hydrogen Sulphide Gas

(adapted from Frost and Lenehan, 2004)

H_2S is colourless, heavier than air, burns with a blue flame and has an odour similar to rotten eggs at low concentrations and a sweetish odour at higher concentrations. Mixtures of H_2S and air may explode violently. Because H_2S is heavier than air, it may accumulate in depressions or spread over the ground to a source of ignition. H_2S is soluble in water, alcohol, ether and hydrocarbons but the water solutions are not stable. The pH of a freshly prepared saturated water solution is 4.5. Hydrogen sulphide is an irritant gas at sub-acute concentrations and a toxic gas at acute concentrations.

H_2S Production from Slurry

(adapted from Frost and Lenehan, 2004)

Dairy cows and beef cattle produce significant volumes of slurry. For example, a dairy cow weighing 450-650kg produces a typical volume of 53 litres per day at 10% dry matter (DARD, 2003). The comparable figure for a beef bullock weighing 200-450kg is 26 litres per day at 10% dry matter (DARD, 2003). Consequently, over six-months of winter housing, a 550kg dairy cow produces 9.6t of undiluted slurry containing 48kg, 19kg and 48kg respectively of nitrogen (N), phosphate (P_2O_5) and potash (K_2O) (MAFF, 2000). Over the same period a 400kg beef animal produces 4.7t of undiluted slurry containing 24kg N, 9kg P_2O_5 and 24kg K_2O (derived from MAFF, 2000).

During storage, slurry which comprises both urine and faeces, undergoes decomposition due to the metabolic action of micro-organisms. Because available oxygen is quickly consumed by the high oxygen demand of the decomposing organic matter, the decomposition is predominately anaerobic (without free oxygen) and various odorous gases and volatile compounds are produced (Westerman et al., 1997). The slurry gases of odour concerns are ammonia (NH_3) and hydrogen sulphide (H_2S), and the volatile compounds are volatile fatty acids, aldehydes, alcohols, amines, mercaptans, indoles and skatoles (ASAE Standards, 1993).

When slurry tanks are left undisturbed, the slurry separates into three distinct layers:

- Solid particles of soil, stones, sand, concrete and undigested feeds, which have higher densities than water, sink to form sediment on the bottom.

- The lighter fractions of feed and bedding float to the top. This floating surface layer on cattle slurry, unlike pig slurry, is deeper than the bottom sediment and because of surface evaporation can form a solid looking crust.
- Between these two layers, there is a relatively fluid layer.

Because of this separation and in order to ensure complete emptying of tanks, it is normal practice to agitate the slurry. During mixing, H_2S, CO_2, CH_4 and NH_3 are released.

Principles of Aeration

Aeration is a process which transfers oxygen into the liquid being aerated. The oxygen transfer process is driven by the pressure differential between air and the fluid being aerated. The partial pressure of the oxygen in the air drives oxygen into the liquid until the pressure of oxygen in the liquid becomes equal to the pressure of oxygen in the air. At this stage the liquid is said to be in equilibrium (or at saturation). The concentration of dissolved oxygen (DO) at this condition is called the saturation concentration. In general, organic solids reduce the oxygen transfer rate.

Oxygen transfer rate is affected by several factors:

1. surface area of liquid in contact with air (oxygen);
2. mixing or turbulence;
3. saturation deficit;
4. influence of other constituents in the liquid.

Principles of Slurry Aeration

(taken from Westerman et al., 1997)

Animal slurry can be oxidised into stable inorganic end products by aerobic bacteria. This may be expressed as:

$$\text{Organics (C, H, O, N, S)} + O_2 \rightarrow CO_2 + H_2O + NO_3^- + SO_4^{2-}$$

Under aerobic conditions, the nitrogen compounds (proteins, peptides and amino acids) are converted to ammonium (NH_4^+) by heterotrophic bacteria (require nourishment from organic substances) and then oxidised by autotrophic bacteria (obtain nourishment from inorganic matter such as NH_4^+) to nitrite (NO_2^-) and then to nitrate (NO_3^-). Sulphur compounds in the waste are converted to sulphate (SO_4^{2-}) in the aerobic environment instead of sulphide and mercaptans compounds (odour causing) in the anaerobic environment. The degree of oxidation depends on the amount of oxygen provided and the reaction time allowed in the treatment process. When aeration is terminated and the dissolved oxygen is depleted, the environment is considered to be anoxic. Under these conditions, nitrate and sulphate function as electron acceptors for facultative bacteria, and are reduced to nitrogen gas (N_2) and hydrogen sulphide gas (H_2S) respectively. The process for oxidising ammonium into nitrate is called nitrification while the process for reducing nitrate to nitrogen gas is called denitrification. The combination of nitrification and denitrification will remove nitrogen from the livestock slurry.

Review of Experiments Investigating Effect of Slurry Mixing on H_2S Production

Patni *et al.*, (2003) measured concentrations of H_2S, NH_3 and CO_2 in twelve commercial swine barns with slatted floors and sub-floor slurry storage pits, prior to, during, and immediately after mixing of slurry, on nineteen different days over a two year period. H_2S was measured at different locations within the barns and within the manure pit exhaust air (where appropriate), using electrochemical cells with continuous data loggers. They found that under normal ventilation conditions concentrations of H_2S remained at acceptable concentrations (acceptability concentrations are presented in figure 1).

Property or characteristic	Manure gas			
	Hydrogen Sulfide	Ammonia	Carbon Dioxide	Methane
Specific gravity	1.2	0.6	1.5	0.6
Odor	rotten egg	pungent	none	none
TLV-TWA ppm[a]	10	25	5,000	none[b]
TLV-STEL ppm[a]	15	35	15,000	none[b]
Hazard level	500	2000	30,000	Footnote b

[a] TLV = Threshold Limit Value; TWA = Time Weighted Average (normally 8 hrs.); STEL = Short Term Exposure Limit (normally 15 minutes); ppm = parts per million by volume
[b] Asphyxiant, forms explosive mixture with air at concentrations of 50,000 to 150,000 ppm (5 to 15%) by volume.

Figure 1 **Properties, characteristics and threshold limit values (TLVs) of manure gases (Patni et al., (2003))**

At the commencement of mixing, immediate and very rapid release of high concentrations of H_2S were observed, and decreased as mixing progressed.

McAllister and McQuitty (1965) reported on a study of over 20 pig farms throughout Northern Ireland that investigated the effects of agitating stored slurry on the atmosphere in buildings and tanks. It was found that the concentration of CO_2, CH_4 or NH_3 never reached concentrations sufficiently high to constitute a serious risk of causing death or even serious injury to pigs. However, the mean concentration of H_2S at slat level during mixing in 10 buildings was 278ppm. This investigation highlighted a rapid rise in H_2S concentration immediately after the start of mixing and a rapid fall in concentration once mixing ceased.

Haarsten (1967), investigating the poisoning of cows by slurry gases found concentrations of H_2S, NH_3 and CO_2 above slurry prior to mixing were 0ppm, 30ppm and 500ppm respectively. During mixing, concentrations were 120-600ppm H_2S, 700ppm NH_3 and 2,000ppm CO_2 at animal level. During mixing of slurry in pig houses H_2S concentrations of 800ppm were recorded above slurry channels and 675ppm at 10 cm above slat level (Skarp, 1971). In cattle houses H_2S concentrations of 80ppm above slurry channels and 30-40ppm at cattle level were found. Slight mixing of slurry was shown to result in a H_2S concentration of 15ppm at 1 to 2 meters above slat level and of more than 200ppm just below slat level (Noreen *et al.*, 1967).

Review of Experiments Investigating Effect of Slurry Aeration on H_2S Production

Aeration of slurry has been shown to be a method of reducing the emission of toxic or malodorous volatiles (Zhang and Zhu, 2005). There have been many studies conducted on continuous aeration of slurry to reduce the formation and emission of volatile organic compounds related to odour (Burton and Sneath, 1995) and some study of short-term aeration to reduce odour potential of manure slurry (Zhang and Zhu, 2005). However, even in these cases the aeration rate is of the order of $1.2L.s^{-1}.m^{-3}$. A study undertaken by Clark *et al.*, (2005), applied airflow rates which were, at maximum, $0.04L.s^{-1}.m^{-3}$. They conducted a bench scale experiment where air was bubbled through 15L swine slurry samples at varying aeration rates for 28 days in digesters. The mean H_2S concentration in the headspace of each digester was $10\mu L.L^{-1}$. After 28 days the slurry was mixed and H_2S readings of $>120\mu L.L^{-1}$ were recorded in some treatments. The authors concluded that low-level bubbling of air through slurry appears to be a viable method for reducing peak H_2S emissions from swine manure slurry at a bench scale. The need for full-scale validation of the findings is highlighted.

H_2S Exposure Limits

The National Authority for Occupational Safety and Health published a Code of Practice for the Safety, Health and Welfare a Work (Chemical Agents) Regulations, 2001 in 2002. In this document, limit values for exposure levels to various chemicals are established. The limits are established in terms of OELV's. OELV is an acronym for Occupational Exposure Limit Values and is defined as; "meaning, unless otherwise specified, the limit of the time-weighted average of the concentration of a chemical agent in the air at the workplace to which the worker may be exposed, in relation to an 8-hour or a 15-minute reference period. The concentration of the chemical agent in air is generally expressed as parts per million (ppm), milligrams per cubic metre ($mg.m^{-3}$) as appropriate.
In the Code of Practice the OELV values for hydrogen sulphide are listed as follows:

Table 1 OELV for hydrogen sulphide (H_2S) gas

Substance			OELV (8 hour REFERENCE period)		OELV (15 minute reference period)	
	EINECS No.	CAS No.	ppm	$mg.m^{-3}$	ppm	$mg.m^{-3}$
Hydrogen sulphide	231-977-3	7783-06-4	10	14	15	21

Data in the following table indicate the physiological response of adult humans to H_2S (Nordstrom and McQuitty, 1976 - compiled from different reference sources).

Table 2 Physiological response of adult humans to hydrogen sulphide

EFFECT	CONCENTRATION (PPM)
Least detectable odour	0.01-0.7
Offensive odour	3-5
Eye irritant	10
Irritation to mucous membranes and lungs	20
Irritation of eyes and respiratory tract (1hr)	50-100
Olfactory-nerve paralysis, fatal in 8-48hr	150
Headaches, dizziness (1hr), nervous system depression	200
Nausea, excitement, insomnia, unconsciousness, possible death (30min)	500-600
Rapidly fatal	700-2000

There are no guidelines for exposure limits for animals. It has been suggested that animal responses are similar to those of humans but vary in intensity with animal weight and duration of exposure (McAllister and McQuitty, 1965; McAllister, 1966; and Taiganides and White, 1969). Therefore, while H_2S will cause the same physiological effects in cattle as in pigs, the effects may not become apparent so readily in cattle because of their greater size and body weight. A fatal concentration for a 68 kg pig is around 800-1,000ppm, while this concentration may cause only nausea and unconsciousness in a 227kg calf (Taiganides and White, 1969).

Objectives of Current Work

- Review existing scientific knowledge on the topic of emissions of hydrogen sulphide (H_2S) gas during low rate aeration of slurry.
- Establish the concentration of H_2S gas produced by slurry which is deposited and stored in underground tanks in slatted floor sheds during the winter animal housing period (conventional slurry management practices).
- Establish the concentration of H_2S gas produced by slurry managed in the same system but also undergoing low rate aeration.
- Compare the H_2S emission rates from normally managed slurry and slurry that has undergone low rate aeration.
- Measure H_2S emission rates from slurry that has undergone low rate aeration during slurry pumping.
- Measure H_2S emission rates from normally managed slurry during mixing.
- Measure H_2S emission rates from mixed normally managed slurry during pumping.

Materials and Methods

Experimental Design

The experimental site selected for this study was Livestock Shed No. 3 at Teagasc Grange Beef Research Centre, Dunsany, Co. Meath, Ireland. The shed was laid out as follows:

The shed was divided by a central passage with six cattle pens on each side of the passage. There were three underground slatted slurry tanks on each side of the feeding passage therefore slurry from every two pens is deposited in one slurry tank. The pens and tanks were named and configured as illustrated in figure 2:

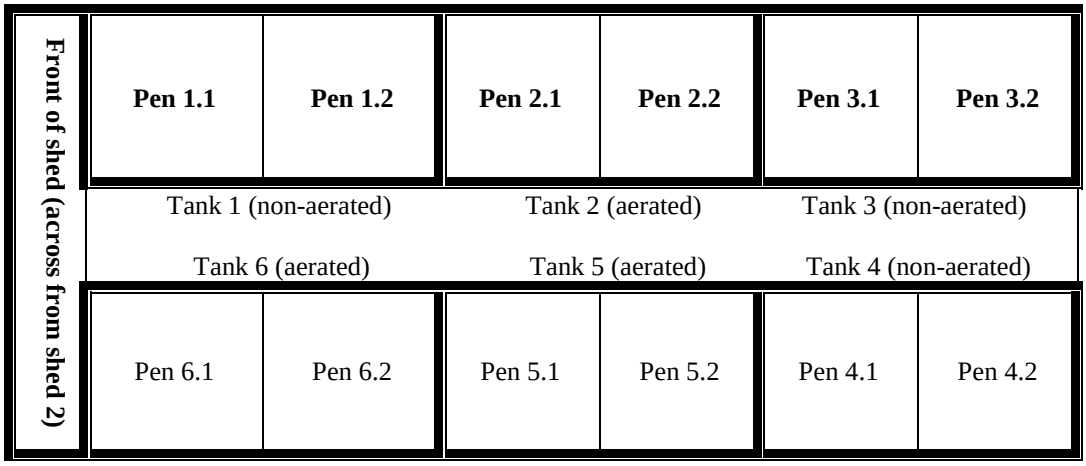

Figure 2 Shed No. 3 Experimental Design (Teagasc Grange)

A low rate slurry aeration system was installed in three of the six slurry tanks. Therefore the design was as follows:

Two treatments

1. Low rate aeration of slurry
2. Normally managed slurry

There were three replicates of each treatment and each treatment was randomly assigned to the slurry storage tanks.

Each of the six slurry tanks was emptied prior to commencement of the experiment. 14 animals (mean liveweight 457kg) were assigned to each pen and were fed on the same diet (silage *ad libitum* + 3kg concentrates per animal per day). The slurry aeration system was not switched on until approximately 0.23m of fresh slurry had been deposited in each tank. Once this level had been reached, the H_2S monitors were installed in each tank and the aeration system switched on. Monitors were removed from the system at regular intervals and the saved data downloaded onto a PC. The monitors were then reset and reinstalled. The experiment ran for 99 days. A flow diagram of the weekly H_2S gas data collection protocol is presented in figure 3:

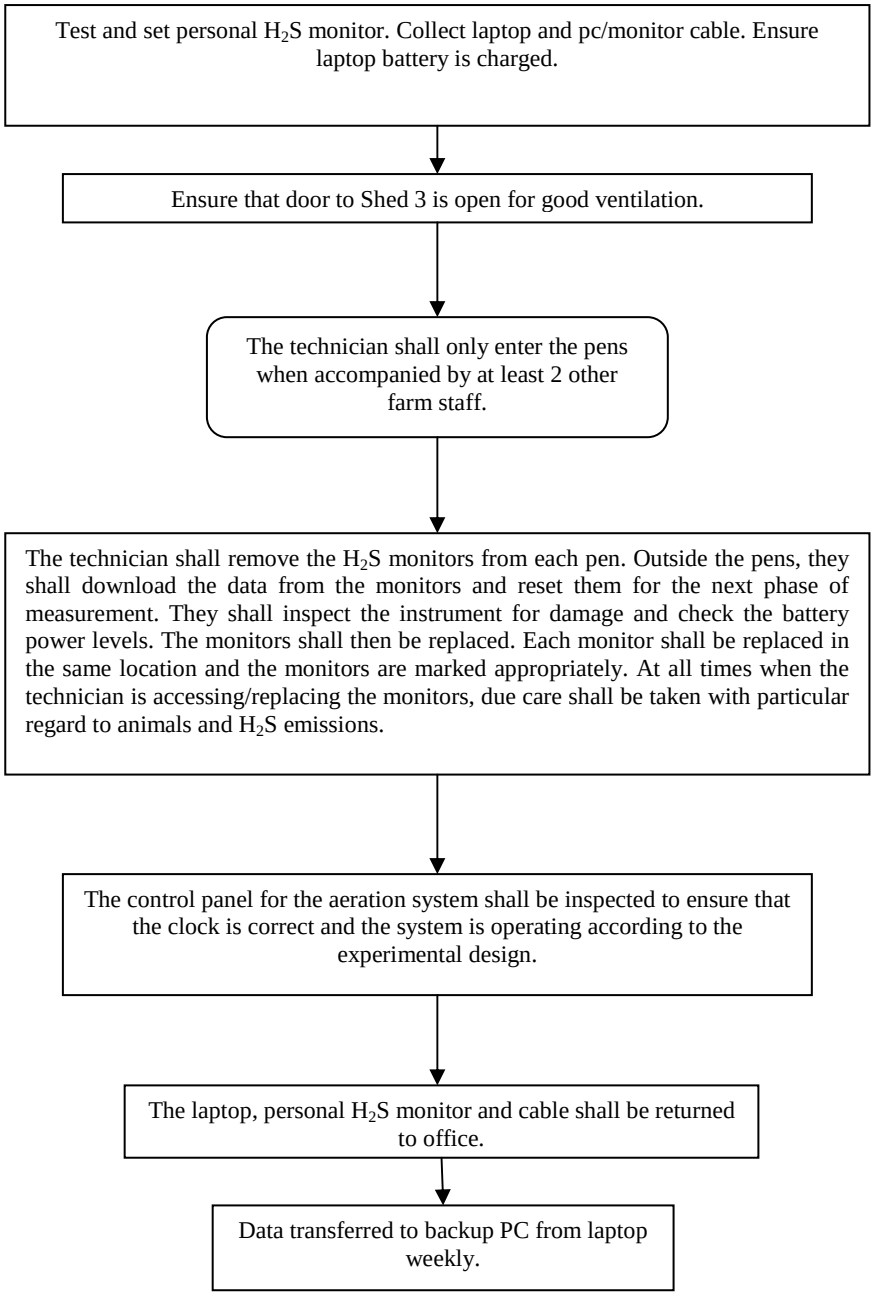

Figure 3 Protocol for weekly collection of H_2S data from monitors

Low Rate Aeration System

A low rate aeration system (Aeromixer) was installed in an annex to the livestock building. An electrically driven compressor generated compressed air, (airflow rate 25 m^3/hr) which was piped through a manifold to three rotary valves (one valve per slurry tank). The rotary valves have a number of outlet ports piped to non-return flap valves located at the base of each slurry storage tank. A control panel together with the rotary valves (which are operated pneumatically) control the distribution of the compressed air. The air was sent to each outlet port for a predetermined time period in a sequential fashion and bubbled upwards through the stored slurry. Two pictures showing the installation of the system in one slurry tank and the compressor and control system are presented in figures 4 and 5:

Figure 4 **Installation of air delivery nozzle system into slurry tank**

Figure 5 **Air compressor, control panel, manifold and rotary valve of aeration system**

Operating Regime of Aeration System

The system was operated for 36 minutes every 2 hours as set by the manufacturer during installation and commissioning. During the 36 minute operation period each air outlet (12 outlets per tank, 3 tanks, and therefore 36 outlets) was operated for 1 minute. Over a 24 hour period each nozzle outlet therefore operated for 12 minutes. The system was controlled by a time clock.

Gas Monitoring Equipment

The concentration of H_2S gas was measured using ImpulsePro portable gas monitors (Zellweger Analytics, UK) fitted with a H_2S electrochemical smart sensor. The monitors were used as a diffusion type monitoring device whereby the atmosphere being measured reached the sensor by diffusing through vents in the sensor compartment cover. Normal air movements were considered sufficient to carry the sample to the sensor, which reacts to the concentrations of the gases being measured. Six monitors were used on each occasion and were set to record H_2S concentrations at varying time intervals ranging from 10 second intervals to 10 minute intervals. The monitors were equipped with data logging capability and were able to store up to 3500 data logging intervals. This meant that at 10 minute interval settings, H_2S readings for up to 24.3 days could be stored in the monitor. The H_2S smart sensor was capable of measuring gas concentrations up to 500ppm. A diagram of one of the gas monitors is presented in figure 6:

Figure 6 **H_2S gas monitor**

Measuring Gas Concentrations

The H_2S gas monitors were installed such that H_2S gas was monitored immediately beneath the invert of the slats where H_2S gas can congregate after mixing/aeration. One monitor was installed over the centre (approximate location) of each tank. The monitor was installed by connecting it to a metal plate which lies over the slats. The monitor was positioned between the slats facing downwards so the sensor was at the invert level of the slats. A diagram of the monitor position within the slat system is presented in figure 7:

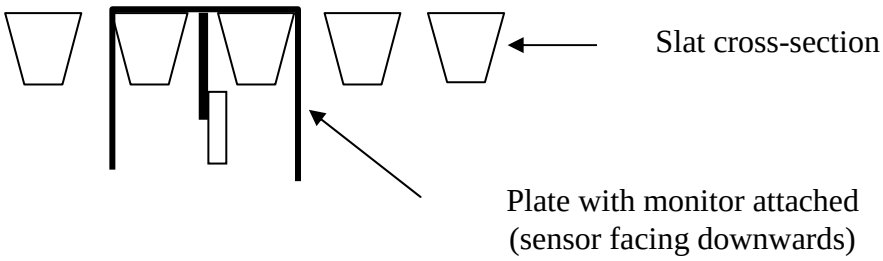

Figure 7 **Typical installation of monitors within the slat system**

Slurry Mixing Equipment

Mixing of stored slurry which had not been aerated was achieved using subsurface circulation with a whisk rather than by means of a jetter pump. The whisk was inserted into the slurry via a tank sump which was external to the livestock building. As is normal in most slurry mixing operations, water was added to the slurry during mixing. A dipstick was used at varying intervals during mixing to assess the viscosity of the mixed slurry. During mixing H_2S monitors were installed at the mixing point and above slat level over the tank containing the slurry being mixed.

Pumping Equipment

Pumping of both the aerated and mixed slurry was undertaken according to normal farm operational practices. The pump was powered by a tractor via a PTO shaft. During pumping of the aerated slurry H_2S monitors were installed at the external sump, over the slurry tank containing the slurry being pumped and at slat level over the tank into which the aerated slurry was being pumped. A picture of a pumping system where slurry is being pumped from a reception pit to an above ground tank is presented in figure 8:

Figure 8 **Slurry pumping from reception pit to above ground tank**

Results

H_2S Emissions during Animal Housing Period

Hydrogen sulphide gas concentrations were measured at slat invert level over a 99-day period from 22 December 2005 until 30 March 2006. Animals were housed in naturally ventilated slatted floor accommodation continuously during this time. 5450 litres of water was added to each of the 6 tanks on 7th February 2006 on the advice of the supplier of the aeration equipment. The H_2S monitors were set to record H_2S concentrations at five-minute intervals.

Non-aerated slurry

The average number of readings per non-aerated tank was 26,121. No H_2S detected during the monitoring period in any of these tanks.

Aerated slurry

Each low rate aeration outlet was set to operate for 1 minute in every 2 hours (i.e. 3 tanks, 12 outlets per tank and one complete cycle of 36 outlets every 2 hours). Therefore, each nozzle operated 12 times per day for a total of 12 minutes per day (0.8% of a day). The monitors were set to record at 5-minute intervals (288 of 5-minute means per day). Due to the heavier than air properties of H_2S and dilution of H_2S concentrations by ambient air, it is suggested that each monitor would have needed to be directly above an aeration outlet in order to register accurately the concentration of H_2S generated above the outlet. In the current work the monitors were not directly above an aeration outlet. In addition, given the 5-minute recording interval of the monitors and the low proportion of total time that each aeration outlet operated, it is possible that H_2S was generated, but not recorded. Consequently, an absence of readings on a monitor did not necessarily indicate that there was no H_2S generated. Furthermore, low readings on a monitor may signify that H_2S had been generated at an aeration outlet distant from the monitor. Again, given the heavier than air properties of H_2S, it is probable that in this circumstance, there could be considerable atmospheric dilution of H_2S concentration prior to recording on the monitor. Therefore, a low concentration of H_2S recorded does not necessarily correspond with a low concentration of H_2S above an aeration outlet.

The average number of recordings per aerated tank was 29,115. H_2S was only detected during the aeration cycle. A summary of the findings for the aerated tanks (tank numbers 2, 5 and 6) is presented below:

Tank 2: H_2S was detected occasionally throughout the monitoring period, but not during the first week of aeration. There was a sustained period of H_2S detection that lasted for 4 days, just after the addition of water on 7th February 2006. This accounted for approximately one third of the number of times H_2S was detected in this tank. Over the 99 day monitoring period, H_2S was detected in 0.5% of the readings, the average of these being 1ppm H_2S and the maximum 5ppm H_2S.

Tank 5: H_2S was detected during the first week of aeration, but not after this. During this first week, 6% of the readings were positive for H_2S, the average of these being 1ppm H_2S and the maximum, 7ppm H_2S. Over the monitoring period, 99% of the readings recorded no H_2S present.

Tank 6: H_2S was detected during the first 40 hours of monitoring in 3.9% of the readings, the average of the readings that detected H_2S was 2ppm and the maximum was 6ppm H_2S. There was no H_2S detected in tank 6 during the remainder of the monitoring period. Only 0.4% of the readings recorded H_2S during the monitoring period.

H_2S Emissions during Pumping of Aerated Slurry

Concentrations of H_2S were measured at two locations during pumping of aerated slurry. For all three aerated tanks (tanks 2, 5 and 6), a monitor was installed at slat invert level over the centre of each slurry tank being pumped from and over the centre of each reception tank being pumped to. A monitor was also placed at ground level at the pumping sump. All monitors were set to record at 10-second intervals.

No H_2S was detected during pumping in the centre of tanks 5 and 6. H_2S was detected at the centre of tank 2 and at reception tanks 2 and 5. The results from these locations are presented in figure 6 and are summarised below. There were differences between the maximum concentrations of H_2S detected during the emptying of the 3 tanks (0 to 30ppm). However, the maximum concentrations recorded were considerably less than the 500ppm plus, recorded in a previous study by the Frost and Lenehan (2004).

Tank 2 and pumping point tank 2: this was the only aerated tank where any H_2S was detected below slat level during pumping and then only infrequently. Only 10% of the readings indicated the presence of H_2S, 80% of these being 1ppm with a maximum of 3ppm H_2S (1 reading). The monitor positioned at slat level at the pumping point in tank 2 recorded concentrations of H_2S >0ppm intermittently during this time. Of the data recorded, 52% of the readings were zero and 42% of the readings recorded between 1 and 5ppm H_2S. There was a small peak (maximum 10ppm) in H_2S after 40 minutes of pumping and again towards the end of pumping after 140 minutes (figure 9). The mean of the readings above zero was 3ppm H_2S with a standard deviation of 2.9 and a maximum of 21ppm H_2S. However, the monitor in the reception tank for slurry pumped from tank 2 did not detect any H_2S.

Tank 5: H_2S detected at the reception sump from tank 5 showed a peak (30ppm) within the first 10 minutes of pumping, with readings quickly reducing to zero after 12 minutes. No H_2S was detected at invert slat level in tank 5, or at the pumping point. This is in contrast to tank 2, where H_2S was detected at the pumping point, but not at the reception point.

Tank6: No H_2S was detected by any of the H_2S monitors during the emptying of this tank

On most farms, slurry is normally taken directly from the source tank to a tanker and then to field, with no pumping to another store first. The results from the current study indicate that there should be little or no risk from H_2S emissions from aerated slurry during pumping. It is recommended that extraction points for slurry from below house tanks should be located outside of buildings. In this scenario, any low concentrations of H_2S generated should quickly be diluted through dispersal in ambient air. It is suggested that during slurry removal by vacuum tanker, the concentrations of H_2S would also be minimal.

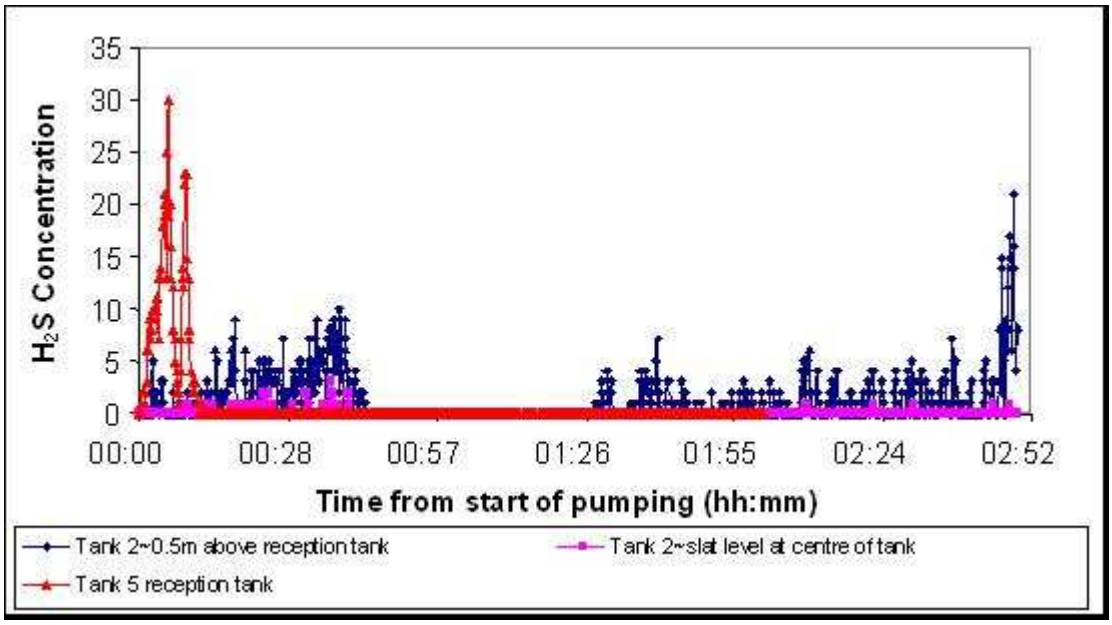

Figure 9 **Concentration of H_2S detected during pumping of aerated slurry at slat level for tank 2, above the pumping point for tank 2 and at slat level of reception tank for slurry being pumped from tank 5.**

H_2S Emissions during Mixing of Non-Aerated Slurry

Due to the heavy consistencies in general of the non-aerated slurries, it was not possible to pump them without mixing first. It was deemed necessary to add water to these tanks and mix them prior to pumping. Water was therefore added during mixing as per normal farm management practices. The slurry was mixed until the operator was satisfied that the slurry was sufficiently mixed for pumping. Tank 1 was mixed for 140 minutes with 7,275 litres of water added. Tank 3 was mixed for 92 minutes with 14,550 litres of water added. Tank 4 was mixed for 30 minutes and no additional water was required.

During mixing, H_2S concentrations were recorded 0.5m above the centre of each tank being mixed. The monitor in tank 1 was set to record at 10s intervals, whilst those in tanks 3 and 4 were set to record at 30s intervals. Table 3 presents a summary of the data recorded.

Table 3 **H_2S concentrations recorded at slat invert level for tank 1 and 0.5m above centre of tanks 3 and 4 during mixing of non-aerated mixed slurry**

Concentration of H_2S	Tank 1	Tank 3	Tank 4
Maximum (ppm)	257	41	5
	Percentage of recordings		
0ppm	4	52	19
1-5ppm	1	39	81
6-10ppm	10	3	0
11-15ppm	13	1	0
16-20ppm	6	1	0
21-50ppm	16	4	0
51-100ppm	20	0	0
101-150ppm	22	0	0
151-200ppm	5	0	0
>200ppm	3	0	0

Tank 4 required very little mixing and no H_2S >5ppm was detected during mixing. H_2S concentration above tank 3 peaked at 41ppm. However 91% of the readings recorded were 5ppm or less. Tank 1 was monitored below slat level for the first 50 minutes of mixing and then at 0.5m above slat level for the next 90 minutes (next day) The readings (figure 10) indicated concentrations of H_2S consistently above 80ppm for the first 30 minutes of mixing, with a peak of 257ppm, but decreasing to 10ppm after 50 minutes. The readings from tank 1, taken 0.5m above slat level when mixing commenced next morning, peaked at 10ppm, with 86% of the readings detecting no H_2S. The high concentrations of H_2S in tank 1 highlight the inherent danger from H_2S emissions during mixing of slurry.

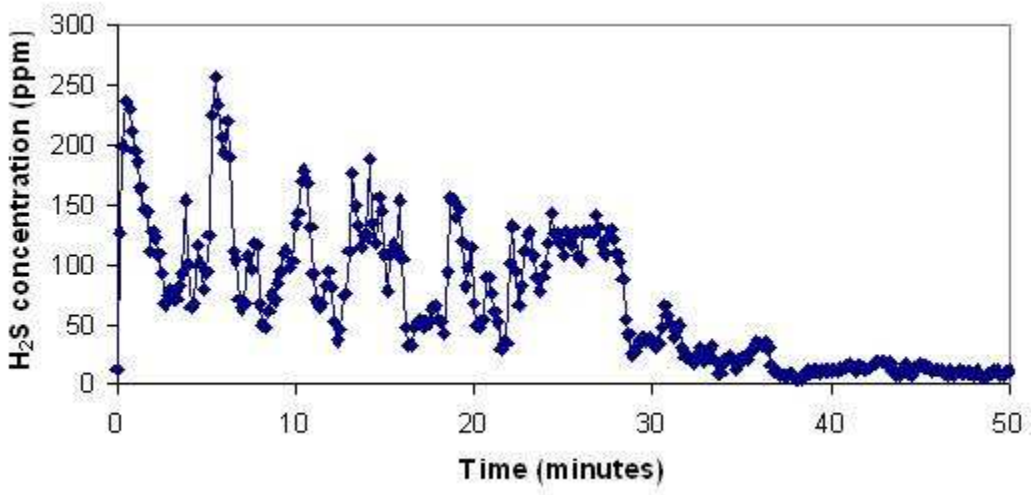

Figure 10 **Concentration of H_2S detected during mixing of non-aerated slurry in tank 1 at slat invert level.**

H_2S Emissions during Pumping of Mixed Non-Aerated Slurry

Following dilution and mixing, the non-aerated slurry tanks were pumped to a reception tank. During pumping of mixed non-aerated slurry, H_2S concentrations were recorded at 0.5m above the slurry tank being pumped from and at slat invert level over the reception tank into which the slurry was being pumped. The monitors were set to record at 30s intervals. Pumping slurry from below ground slatted tanks is practised when open top slurry tankers are employed. When slurry is removed by vacuum slurry tankers, the slurry is drawn to the suction point. Where an external sump is utilised it is likely that for both methods of slurry removal, similar H_2S emissions would occur.

The data in table 4 present a summary of the H_2S concentrations recorded 0.5m above the centre of tanks 1, 3 and 4 during pumping of non-aerated mixed slurry. Over the periods of pumping, the peak concentrations of H_2S recorded were 107ppm (tank 1), 2ppm (tank 3) and 44ppm (tank 4). The percentage of time that concentrations were above 15ppm for tanks 1, 3 and 4 were respectively 2%, 0% and 27%. Only in tank 1 were concentrations of H_2S detected above 50ppm and this was for a total of 1% of the time.

Table 4 **Concentrations of H_2S detected during pumping of non-aerated slurry at 0.5m above the centre of tanks 1, 3 and 4**

Concentration of H_2S	**Tank 1**	**Tank 3**	**Tank 4**
Maximum (ppm)	107	2	44
	Percentage of recordings		
0ppm	37	76	7
1-5ppm	50	24	23
6-10ppm	10	0	20
11-15ppm	1	0	23
16-20ppm	0	0	18
21-50ppm	1	0	10
51-100ppm	1	0	0
101-150ppm	0	0	0
>150ppm	0	0	0

The majority of readings (76%) above tank 3 were zero and even when H_2S was detected, the concentrations were below 5ppm.

The recorded concentrations of H_2S below the slats in the centre of the reception tanks (table 5) showed a similar pattern to that recorded above the source tank (table 4).

Table 5 **H_2S concentrations recorded in centre of reception tanks beneath slat level during pumping of non-aerated mixed slurry**

Concentration of H_2S	Tank 1	Tank 3	Tank 4
Maximum (ppm)	3	13	102
	Percentage of recordings		
0ppm	90	80	0
1-5ppm	10	19	2
6-10ppm	0	.5	2
11-15ppm	0	.5	2
16-20ppm	0	0	4
21-50ppm	0	0	40
51-100ppm	0	0	47
101-150ppm	0	0	3
>150ppm	0	0	0

The data in figure 11 indicate the concentrations of H_2S over time that were detected 0.5m above slat level for tank 1 and at slat invert level for tank 4 during emptying.

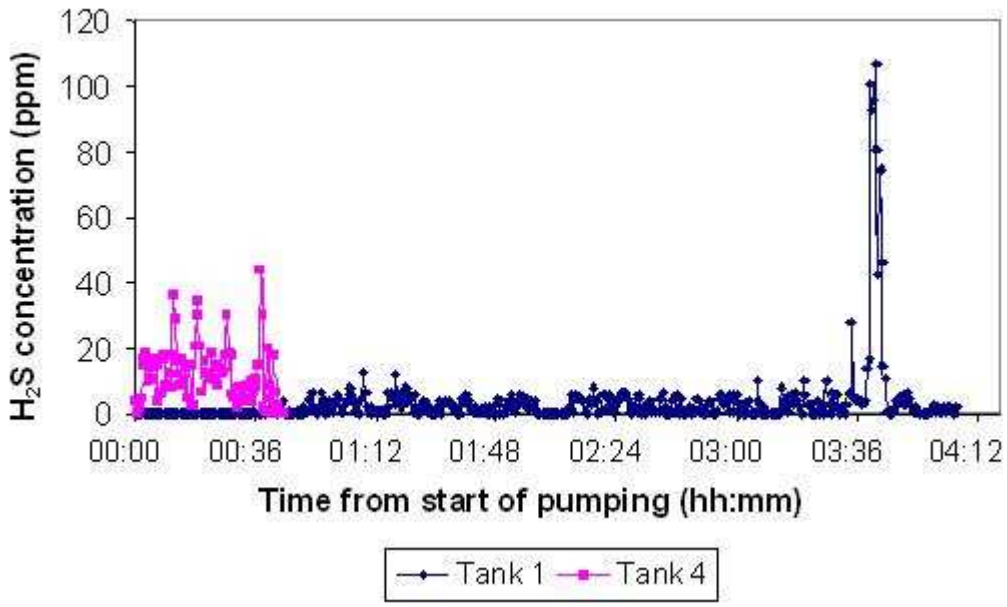

Figure 11 **H_2S concentrations recorded 0.5m above centre of tank 1 and at slat invert level for tank 4 during pumping of non-aerated mixed slurry**

H_2S was detected 0.5m above tank 1 after 40 minutes of pumping for the next 170 minutes, up to a maximum of 13ppm. After this period there was a sudden and unexplained increase to the maximum level recorded of 107ppm. The H_2S emissions recorded from tank 4, measured 0.5m above slat level during pumping, were much higher than for the other two non-aerated tanks. This contrasts with the H_2S concentrations recorded during mixing of tank 4, where the highest concentration of H_2S recorded was 5ppm and highlights the variability of H_2S emissions from the same source of slurry. The maximum level of H_2S recorded 0.5m above tank 3 was 2ppm, with 75% of the readings detecting no H_2S.

The H_2S concentrations recorded at slat invert level in the reception tanks, summarised in table 5, show that the concentrations recorded from tanks 1 and 3 were all less than 6ppm, with the exception of two readings of 6 and 13ppm. The reception tank for tank 4 peaked at 102ppm, with 47% of the readings above 50ppm (23 minutes). This is in line with the concentrations recorded above tank 4 during pumping (table 4 and figure 11). The variation in concentration of H_2S with time during pumping is indicated in figure 12. The concentration of H_2S fluctuated around 50ppm throughout the duration of pumping.

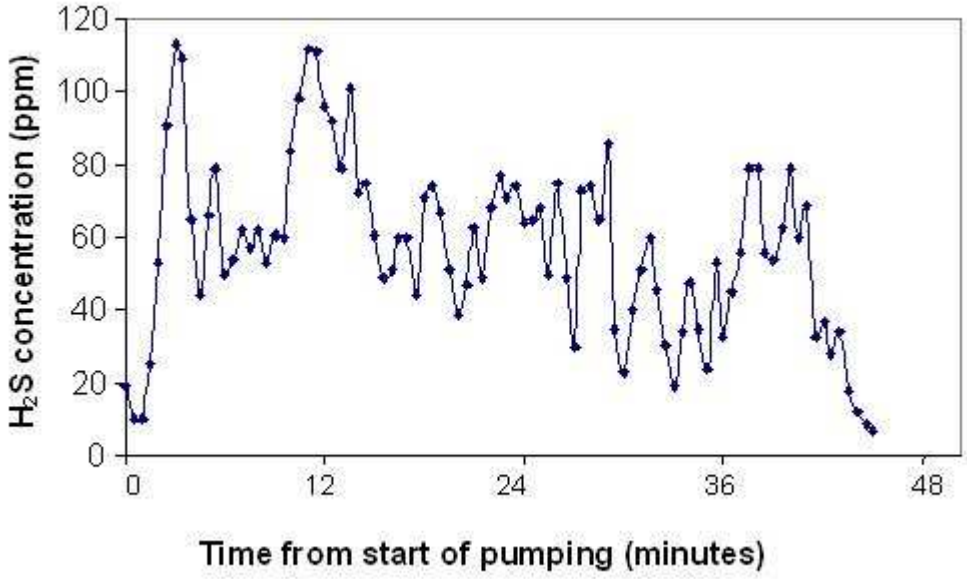

Figure 12 **H_2S concentrations recorded in centre of reception tank beneath slat level during pumping of non-aerated mixed slurry from tank 4.**

H_2S Concentrations Measured in Surveyed Farms

Three dairy farms in Northern Ireland with slat covered slurry tanks fitted with low-rate aeration systems were monitored for H_2S production during April to June 2005. For each farm, two H_2S data-logging monitors were installed just below slat level and left there for approximately one week. The monitors were set to record H_2S concentrations at 5-minute intervals. This process was repeated on three separate occasions for each of the three farms. Thus, a total of 9 weeks of data were gathered.

Mixing time on the farms varied from 3 hours per day to 7 hours per day. Figure 13 indicates that production of H_2S was restricted to the hours of aeration and that no H_2S was produced when the aerators were not operating. The five-minute peak concentrations of H_2S recorded by the data loggers (table 6) indicated one farm with a maximum of about 74ppm and more typically peaks of 30ppm or less. The absolute peak value for H_2S concentration recorded (table 6) was 119ppm. The concentrations of H_2S, as percent of total aeration time, varied between meter location, farms and weeks. The maximum time that concentrations were above 10ppm was approximately 10% of the total aeration time (2% of total elapsed time). There were number of aeration outlets throughout the tank, only two monitors per tank and each monitor was set to record at five minute intervals. It is therefore reasonable to conclude that during aeration, there could have been a constant concentration of H_2S (>10ppm) below slat level throughout the houses. The data presented in figure 10 and table 6 suggest that the OELV 15 minute reference period of 15ppm was exceeded at some stage on every

farm. The average duration of this excess at each monitor was 1.1% of total aeration time (standard deviation = 1.23). For each monitor this equates to approximately 4 minutes per day (26 minutes over approximately 7 days). As indicated above, it is probable that during aeration the proportion of aeration time that exceeded 15ppm H_2S below slat level throughout the house would have been greater. Above slat level it is likely that concentrations of H_2S would be considerably lowered through dilution with ambient air.

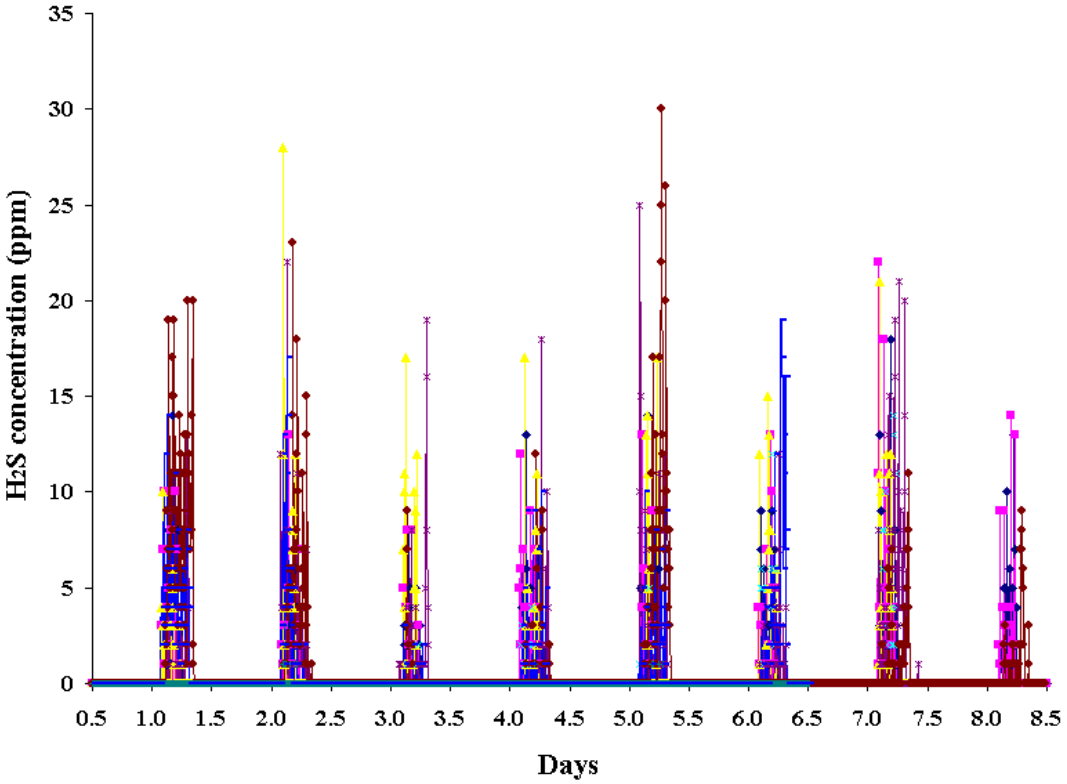

Figure 13 **Pattern of H_2S production on three farms in Northern Ireland over a total period of nine weeks.**

Table 6 Summary of H_2S concentrations over three weeks on each of 3 farms in Northern Ireland

	Farm 1 Week 1	Farm 1 Week2	Farm 1 Week 2	Farm 1 Week 3	Farm 1 Week 1	Farm 2 Week 1	Farm 2 Week 1	Farm 2 Week 2	Farm 2 Week 2	Farm 2 Week 3	Farm 3 Week 1	Farm 3 Week 1	Farm 3 Week 2	Farm 3 Week 3	Farm 3 Week 3
Total aeration time (TAT)	35.0h	63.0h	63.0h	49.0h	49.0h	49.0h	56.0h	56.0h	42.0h	42.0h	24.0h	24.0h	18.0h	21.0h	21.0h
% TAT >0ppm	0.0	43.0	20.5	92.5	0.2	43.5	5.5	40.6	3.8	40.1	49.7	54.2	1.9	38.5	23.0
% TAT >10ppm	0.0	6.5	0.4	7.3	0.0	4.3	0.0	6.8	0.0	4.2	2.8	5.2	0.0	9.5	2.0
% TAT >15ppm	0.0	2.0	0.3	3.9	0.0	1.9	0.0	2.7	0.0	1.8	0.3	0.7	0.0	2.4	0.0
% TAT >20ppm	0.0	0.8	0.0	2.2	0.0	0.7	0.0	1.3	0.0	0.0	0.0	0.3	0.0	0.8	0.0
% TAT >25ppm	0.0	0.1	0.0	1.5	0.0	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0
% TAT >30ppm	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% TAT >40ppm	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% TAT >50ppm	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 min maximum (ppm)	0	25	19	74	1	25	2	30	3	19	18	22	1	28	14
Absolute peak (ppm)	1	66	33	119	2	56	5	50	7	38	58	69	6	81	53
% Elapsed time >10ppm	0.0	1.9	0.1	2.1	0.0	1.2	0.0	2.0	0.0	1.2	0.3	0.7	0.0	1.2	0.2

Discussion

General

The gas monitors that were used for this experiment generally performed very well. Due to the location of the monitors at slat invert level, there were occasions when slurry splashed or fell onto the monitors. It was felt that collection of gaseous concentrations at or beneath slat level was potentially problematic with such a system. Use of an aspirated sample collection system whereby samples of the air at the target location are collected and pumped to the sensor would seem to be a preferable option. Data collection was further hindered by the presence of livestock standing/lying on the slats under which the monitor was located. It is preferable that persons should not enter pens containing livestock if at all possible from a health and safety perspective.

H_2S Emissions during Animal Housing Period

Observations of the surface condition of the slurry stored in both treatments were made over the housing period. Slurry samples were taken to estimate the homogeneity and viscosity of the slurries. On 5th February 2006, the aerated slurry had a high viscosity and, although visually homogeneous, it was considered that aerated slurry pumping could be problematic. After consultation with the aeration system manufacturer, 5450 litres of water was added to each tank on 7th February 2006.

No H_2S was detected in the non-aerated tanks during the 99 day animal housing period. In the aerated tanks, over 99% of the readings detected no H_2S.

In aerated tank 2, occasional concentrations of H_2S > 0ppm were recorded during the 99 day housing period and of these, the maximum concentration recorded was 5ppm and the average was 1ppm. Water addition on 7th February appeared to result in a slight elevation in H_2S emissions, although these were less than 5ppm at all times.

In tank 5 and tank 6 concentrations of H_2S gas of up to 7ppm were recorded in the first few days after commencement of the experiment. However, once the system was established, H_2S concentrations >0ppm were only recorded occasionally.

It is concluded that low-rate intermittent aeration of beef cattle slurry resulted in low concentrations (maximum 7ppm) of H_2S gas being emitted during the animal housing period. It is important however to note that aeration was monitored over the housing period and there were no prolonged periods where aeration did not take place. In a farming situation, power cuts or machinery breakdowns could result in periods where aeration of slurry would not be possible. Crusting of the slurry could take place and consequently H_2S could conceivably build up beneath the crust. In such situations, high concentrations of H_2S gas could be emitted when the aeration system is restarted. It is prudent therefore, to take the same health and safety precautions as would be necessary when handling normally managed slurry in such situations.

It is also important to note that monitoring intervals of 5-minutes were used to record H_2S concentrations at slat invert level and that the monitors were centralised within each tank, rather than located directly above the aeration nozzle outlet points. Therefore, it is possible that H_2S gas may have been generated within the tanks, but not recorded by the monitors.

Furthermore, the relative distances between the outlet nozzles and the monitors may have resulted in diluted concentrations of H_2S gas being recorded.

H_2S Emissions during Aerated Slurry Pumping

H_2S gas concentrations were measured at slat invert level and at the slurry pumping point in each of the three aerated slurry tanks. The slurry was pumped to a reception pit. H_2S gas concentrations were also measured at the reception point.

During pumping of the slurry from tank 2 to the reception pit, 90% of the H_2S gas concentrations were recorded at 0ppm. Of the other readings recorded, 80% were 1ppm and the highest reading was 3ppm. At the pumping point, low concentrations of H_2S gas were recorded intermittently, but in general readings did not exceed 0ppm. At the reception pit, readings of 0ppm were recorded 52% of the time; concentrations between 0ppm and 5ppm were recorded 42% of the time and concentrations greater than 5ppm 6% of the time.

Pumping from tank 5 resulted in elevated concentrations of H_2S gas at the reception pit (maximum value 30ppm) in the first 12 minutes of pumping but concentrations reduced to 0ppm after this period. No H_2S gas readings were recorded at slat invert level or pumping point of tank 5. No readings were recorded at any of the gas monitor locations during pumping of tank 6.

In general, H_2S gas concentrations were elevated at the pumping point and reception tank for the first few minutes after commencement of pumping (peak tank 2 H_2S reading 21ppm at 40 minutes and peak tank 5 H_2S reading 30ppm at 10 minutes). However, 99% of readings were less than 5ppm and were considered unlikely to be a health and safety risk based on these results. Both the pumping point and reception tanks were outside the building and any H_2S at ground level would have been diluted at head level. Therefore the risk to stock in the building, or people at the slurry movement points was considered to have been very low.

H_2S Emissions during Non-Aerated Slurry Mixing

In tank 1 high H_2S concentrations up to 257ppm were recorded, which could have posed a significant health risk. More than 86% of the 181 readings taken during the first 30 minutes of mixing in tank 1 were greater than 50ppm and more than 50% of the readings were greater than 100ppm. In tank 3, concentrations reached 44ppm 0.5 m above slat level in the first 10 minutes of mixing but decreased to less than 5ppm for the remainder of the mixing period. A maximum H_2S gas reading of 5ppm was recorded during mixing of tank 4 with an average reading of 2ppm.

The results indicate that initial H_2S emissions after commencement of mixing of non-aerated slurry were elevated (maximum concentration of 257ppm recorded) and posed a risk to health and safety, particularly at slat level over the slurry tanks. Hand held personal H_2S monitors were sporadically placed at mixing points during mixing (0.5 m above ground level). Occasional elevated concentrations of H_2S emissions were recorded. Based on the findings, current advice on managing slurry should be continued, particularly with regard to animal movements, evacuation of buildings and working in confined spaces. Operators of mixing equipment could find it useful to carry a personal H_2S monitor.

H_2S Emissions during Pumping of Mixed Non-Aerated Slurry

Examination of the results obtained during this phase of the experiment shows that there were differences in H_2S gas concentrations recorded during pumping from each of the three tanks to the reception pit. H_2S concentrations measured at slat invert level for tank 1 were between 0 and 107ppm and concentrations recorded 0.5m above centre of tanks 3 and 4 were between 0 ~ 2ppm and 0 ~ 44ppm respectively until the end of pumping. Measurements taken above tank 4 showed elevated H_2S gas concentrations throughout pumping ranging from 0 ~ 44ppm with an average reading of 12ppm. Whilst it is difficult to draw firm conclusions based on these data, it is clear that there is the potential for sudden H_2S emissions above the non aerated mixed slurry tanks. H_2S gas concentrations at the reception tank were low for pumping from tanks 1 and 3 (0 ~ 4ppm) but were elevated during pumping from tank 4 (range 7 ~ 102ppm). Such concentrations could pose a risk to personnel.

H_2S Concentrations Measured in Surveyed Farms

Data from the farms surveyed in Northern Ireland indicate that during aeration there was release of H_2S below slat level. Above slat level it is likely that concentrations of H_2S would have been lowered by dilution with ambient air. Placement of dataloggers and datalogging interval may have resulted in some H_2S concentrations not being recorded. The data recorded indicated that H_2S produced during low rate aeration of cattle slurry was at sub-lethal concentrations. The levels of H_2S recorded on the surveyed farms were much higher than those recorded at the Grange research site. This may in part be due to the fact that the livestock on the surveyed farms were dairy cows, whereas the animals on the Grange site were store beef cattle. The aeration cycle was also different at the Grange site, compared to the surveyed farms and this may have had an influence on the detection of H_2S. The concentrations of H_2S recorded in the current work were considerably less than those recorded by Frost and Lenehan (2004) during mixing of non-aerated slurry tanks.

The results presented indicate that concentrations of H_2S produced during low rate aeration were much less than those produced during conventional mixing of non-aerated slurry tanks. Nevertheless, on one farm during one week, the 5-minute maximum concentration of H_2S recorded below the slats was in the range that could cause irritation of eyes and respiratory tract (50-100ppm). On the same farm in the same week the absolute peak concentration recorded approached the level that could cause olfactory-nerve paralysis (150ppm). However, the duration of these concentrations was less than those necessary to cause these problems. On no occasion were concentrations recorded that were at or above lethal level (>500ppm).

It is not possible to conclude from the results of this current on-farm study that concentrations and durations of H_2S above slat level during low rate aeration do not pose health risks. However, from the data presented it is suggested that low rate aeration has potential to aid slurry management in below slat tanks without producing dangerous concentrations of H_2S within the house above slat level.

Conclusions

1. During 99 days of animal housing in three slatted pens above conventional non-aerated below ground slurry tanks, there was no H_2S recorded at slat invert level.
2. During 99 days of animal housing in three slatted pens above below ground slurry tanks fitted with low-rate intermittent aeration systems:
    a. Some H_2S was produced (less than 1% of the recordings) and concentrations were less than the OELV 8-hour exposure limit of 10ppm (maximum concentration recorded 7ppm);
    b. During the first few days following start-up of the aeration system, H_2S concentrations were higher than for the remainder of the housing period (maximum 7ppm H_2S);
    c. Disturbing slurry through addition of water (5% of tank volume) on day 47 resulted in some release of H_2S (maximum 5ppm);
3. H_2S was only detected in one aerated slurry tank (tank 2) at slat invert level immediately after commencement of aerated slurry pumping (maximum 3ppm). It is concluded that pumping aerated slurry from tanks under slats presents a low risk of H_2S toxicity.
4. Mixing of non-aerated beef cattle slurry resulted in elevated concentrations of H_2S gas being recorded at slat invert level. Although variable concentrations were recorded for the three non-aerated tanks during mixing (maximum concentrations: 257ppm for tank 1 at slat invert level; 44 and 5ppm at 0.5m above slat level for tank 3 and 4 respectively), it cannot be assumed that dangerous concentrations of H_2S gas will not be released during mixing. Based on the results obtained in this phase of the study, it is concluded that current best practice advice as laid out in the HSENI publication “Slurry gases can kill” (March 2005) should be adhered to.
5. Pumping of mixed non-aerated slurry from the slatted tanks to a reception pit resulted in H_2S gas concentrations of up to 107ppm being recorded at slat invert level. It is concluded that there is a risk of elevated H_2S emissions during transfer of mixed non-aerated slurry.

Appendix: Nutrient and Homogeneity Study

The experiments reported in the main body of this report form part of a larger study of low-rate intermittent aeration systems. Some aspects of the other experiments are summarised in this appendix.

Introduction

Slurry contains nutrients, which can directly substitute for purchased inorganic fertiliser. Indeed, it is recommended that where possible, slurry (organic fertiliser) is recycled within the agricultural system. Slurry stratifies when stored. Suspended matter of higher density accumulates as sludge at the base of the tank and lighter fibrous material tends to form a crust at the liquid surface. Slurry must therefore be mixed prior to removal and application to land and also to ensure tanks can be completely emptied. During land spreading of slurry, it is desirable that the slurry being spread is as homogeneous as possible, thereby enabling equipment to apply slurry evenly and to match the application rate to the nutrient requirement of the crop.

While equipment is available, e.g. trailing-shoe and band-spreaders, to improve accuracy of application and mitigate the losses associated with ammonia volatilisation and odours, slurry management methods often do not maximise the use of its nutrients. Slurry is commonly stored in under-floor tanks in slatted accommodation.

Low-rate intermittent aeration systems have the potential to maintain the stored slurry in a mixed state, which can be removed from the store without requiring further mixing. As well as keeping the slurry in a mixed state, the addition of oxygen will potentially alter the chemical forms of the nitrogen, phosphorus and sulphur content of the material.

Objectives

The three main objectives of the study were to:

(i) quantify the efficiency of mixing achieved by low-rate intermittent aeration,

(ii) establish what chemical changes (if any) take place in the slurry following low-rate intermittent aeration.

Materials and Methods

Site description

The site is as described in the materials and methods section of the main report.

Slurry sampling immediately after animal housing period

One of the main objectives of the study was to assess the homogeneity of aerated slurry and compare it to conventionally managed stored slurry. It was determined that a number of slurry samples needed to be taken, both at different depths within the slurry tanks and at varying distances from the feed face. Slats over all six tanks were lifted and one-litre slurry samples were collected. The samples were taken in an X pattern (vertical position) from front to back of the tank and from back to front of the tank (12 – 16 samples from each tank). The samples were immediately transported to a freezer for storage. Slurry samples were analysed for hydrogen ion concentration (pH), dry matter concentration (DM) and electroconductivity (EC). It was considered that these three parameters were most appropriate for evaluating the homogeneity of the cattle slurry throughout the slatted tanks.

Aerated slurry pumping
Aerated slurry was pumped from each slurry tank into a reception sump. The sump was then emptied into an above ground slurry store. Pumping of the aerated slurry was undertaken according to normal farm operational practices. The pump was powered with a tractor, via a PTO shaft. During the transfer of aerated slurry from the three aerated slurry tanks, one-litre slurry samples were taken at the pump outlet at varying time intervals, to evaluate homogeneity during transfer.

Management of non-aerated slurry
The first task was to establish that non-aerated slurry did indeed require mixing. Slurry was pumped from a non-aerated tank into a reception sump. Initially the pumped slurry was very watery, but soon increased in viscosity to the point that pumping was almost at a standstill. The pumped slurry was then returned to the original tank for mixing. Mixing of stored slurry that had not been aerated, was achieved using subsurface circulation with a whisk rather than by means of a jetter pump. The whisk was inserted into the slurry via a mixing point that was external to the livestock building. As is normal in most slurry mixing operations, water was added to the slurry during mixing. A dipstick was used at varying intervals during mixing to assess the viscosity of the mixed slurry. After mixing, slurry was pumped to a reception tank in the same manner as that described for aerated slurry. During the transfer of the non-aerated slurry from the three slurry tanks, one-litre slurry samples were taken at the pump outlet at varying time intervals, to evaluate homogeneity during transfer.

Results

Homogeneity of aerated and normally managed slurry immediately after housing period
The data are presented in table 7, which clearly shows that the standard deviations of the samples taken from the aerated tanks are much lower, compared to the non-aerated tanks. This is particularly evident in the dry matter (DM, g/kg) of the samples, which are plotted in figures 14 and 15. Figure 10 displays the variations in the normally managed slurry DM and figure 14 the aerated data. The graphs clearly show that DM values for the aerated slurry samples were more homogeneous than for samples taken from the non-aerated slurry.

Table 7 **Analysis of slurry samples taken at various depths from the aerated and non-aerated tanks after the end of the housing period.**

	Aerated			Non-aerated		
Tank	2	5	6	1	3	4
Dry Matter						
mean	97.4	84.1	92.2	118.7	105.8	95.4
min	92.3	76.5	81.9	79.6	49.4	27.4
max	117.0	94.7	105.8	140.4	141.5	133.6
stdev	6.44	3.77	7.00	19.55	28.11	33.73
Electroconductivity						
mean	36.6	34.3	34.8	31.0	37.6	30.6
min	32.7	31.9	31.9	19.5	34.2	24.9
max	40.9	38.7	38.5	39.1	44.1	34.3
stdev	1.90	1.85	1.67	5.38	2.94	2.37

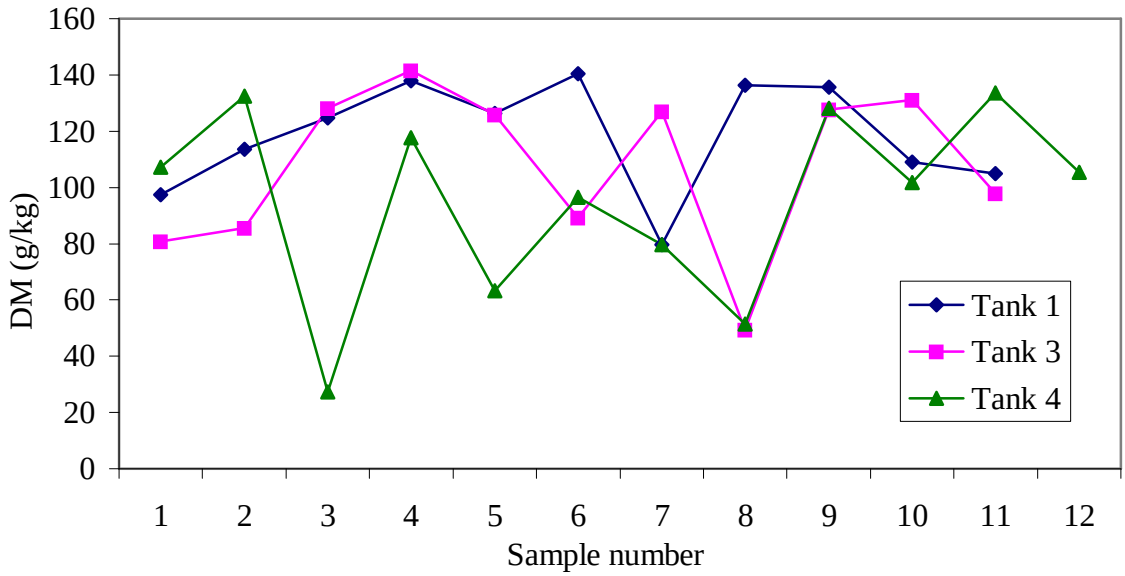

Figure 14 **Dry matter of slurry samples taken from normally managed slurry tanks at various depths after animal housing period**

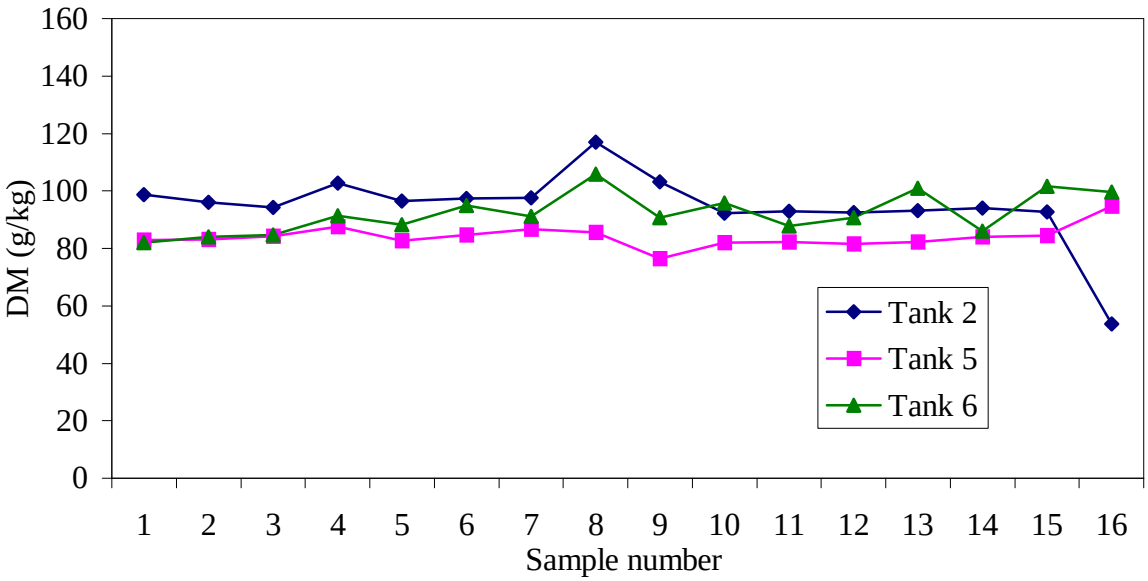

Figure 15 **Dry matter of slurry samples taken from aerated slurry tanks at various depths after animal housing period**

Homogeneity of pumped slurry

During transfer of slurry from each tank to the reception tank, slurry samples were taken from the pump outlet point at varying times through the pumping sequence for analysis, to determine whether the slurry was homogeneous throughout the pumping cycle. The results, which are presented in table 8, show that there are only small variations in the DM and EC of the samples taken during pumping for both the aerated and non-aerated slurry tanks.

Table 8 **Analysis of slurry samples taken during emptying of the aerated and non-aerated tanks.**

	Aerated			Non-aerated		
Tank	2	5	6	1	3	4
Dry Matter						
mean	98.4	84.5	90.4	93.6	92.4	78.2
min	93.2	84.0	86.0	85.1	81.6	77.8
max	101.6	87.1	97.3	101.1	98.3	78.8
stdev	2.57	1.40	3.82	4.74	9.36	0.46
Electroconductivity						
mean	36.6	33.9	34.4	31.9	31.2	30.0
min	34.3	31.8	32.2	29.4	26.1	29.7
max	37.7	36.0	36.0	33.0	34.0	30.5
stdev	0.99	1.28	1.11	1.21	4.45	0.35

Slurry nutrient concentration
Sub-samples were collected from all samples taken at varying times during pumping from the slurry tanks. Using these sub-samples, composites of the pumped slurry from each tank were produced (6 composite samples, 1 per tank). These composite samples were subjected to full nutrient analysis to determine the nutrient concentration of the slurry pumped from each tank. Results are presented in table 8. Samples were frozen prior to transport to laboratory for analysis. pH values measured in the laboratory may not reflect the pH of the fresh slurry, particularly the aerated slurry and have therefore been omitted from table 9.

Table 9 Nutrient analyses of composited pumped slurry samples

			g/kg dry matter (DM)								
	Tank No.	DM (g/kg)	NH_3	N	EC	K	P	TSP	S	Ca	Mg
Non-aerated	1	91.9	26.2	44.5	32	57	7.8	0.88	5.9	19.7	4.7
Non-aerated	3	92.6	27.0	46.0	33	58	9.2	1.11	6.0	22.5	5.3
Non-aerated	4	77.2	30.4	48.5	32	66	7.7	0.82	5.9	19.1	4.4
Aerated	2	96.5	28.2	48.8	37	61	7.6	0.92	6.0	17.7	4.8
Aerated	5	82.8	32.1	50.5	35	67	7.9	0.98	5.5	18.6	4.8
Aerated	6	88.6	29.5	48.1	33	66	7.9	1.02	6.4	19.7	4.6
Non-aerated mean	-	87.2	27.9	46.3	32	60	8.2	0.94	5.9	20.4	4.8
Aerated mean	-	89.2	29.9	49.1	35	65	7.8	0.97	6.0	18.7	4.7

Discussion

Homogeneity of aerated and normally managed slurry immediately after housing period
DM and EC analyses of slurry samples taken from various depths and distances from the feed face in all six tanks indicate that there is less variability in the slurry stored in the aerated tanks than in the non-aerated tanks. Stratification of stored slurry did not appear to occur in the aerated slurry tanks, whereas some stratification was evident in the non-aerated tanks. It can therefore be concluded from this study that low-rate intermittent aeration does maintain slurry in a homogeneous state with respect to dry matter (DM) and electroconductivity (EC).

The study also demonstrated that aerated slurry (with 5% of tank volume containing added water) did not require mixing prior to transfer. This finding has implications for farm management. The ability to remove slurry from a storage tank, particularly towards the end of the animal housing period, without the need for additional mixing, could be of benefit to the farmer, particularly if the housing period is extended beyond what might be expected due to external factors (inclement weather etc.).

This study examined stored slurry immediately after the animal housing period. It is important however to note that aeration was monitored over the housing period and there were no prolonged periods where aeration did not take place. In a farming situation, power cuts or machinery breakdowns could result in periods where aeration of slurry would not be possible and slurry stratification could take place.

Homogeneity of pumped aerated and mixed non-aerated slurry
DM and EC analyses of slurry samples taken from the pump outlet during transfer of both aerated and mixed non-aerated slurry indicate that both systems produce homogeneous slurry.

Low-rate intermittent aeration resulted in slurry with the same homogeneity as mixed non-aerated slurry.

Slurry nutrient concentration
To enable comparisons between various nutrient concentrations for aerated and non-aerated mixer slurry, the concentrations were expressed in terms of the dry matter (DM) concentrations. The results presented in table 9 were statistically tested to compare the difference between treatments (aerated and mixed non-aerated) using a two-sample paired t-test. The tests indicated that treatment had no effect (at the 95% significance level) on the nutrient concentration of the slurry samples.

Conclusions

1. Dry matter (DM) and electroconductivity (EC) analyses of aerated slurry taken from various depths and distances from the feed face in all six tanks, indicated that there was less variability in the slurry stored in the aerated tanks compared to the non-aerated tanks. Low-rate intermittent aeration maintained slurry in a homogeneous state with respect to DM and EC.
2. DM and EC analyses of slurry samples taken from the pump outlet during transfer of both aerated and mixed non-aerated slurry indicate that both systems produce homogeneous slurry. Low-rate intermittent aeration resulted in slurry with similar homogeneity as mixed non-aerated slurry.
3. The results indicated that low-rate intermittent aeration had no significant effect (at the 95% level) on the nutrient concentrations in the slurry.

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