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Combined Aerobic and Electrolytic Treatment of Cattle Slurry

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Handling and use of raw cattle slurry can cause environmental and health problems. These may be solved by improving its physical, chemical and biological characteristics. As the slurry usually needs to be stored for long periods before spreading, methods for improving its quality, combined with storage, are considered in this paper.

A total volume of 60 m^3 of cattle slurry was aerated in a 10 m^3 reactor and stored for 45 weeks in two covered concrete tanks, each of 30 m^3 capacity. The slurry in one tank was exposed to an electrolytic treatment, while in the other, no further treatment was given. In a third tank of similar design, raw slurry was stored without any form of treatment.

The content of thermotolerant coliform bacteria (TCB) was reduced from 10^4 TCB/g of slurry to below 10^2 TCB/g during the 7 d treatment in the aerobic reactor. No new TCB growth was detected during the following 45 week storage period. The electrolytic treatment seemed to ensure an effective pathogen kill. Also raw slurry achieved $< 10^2$ TCB/g after 23 weeks of storage.

Aeration reduced the odour considerably compared with raw slurry. Additional electrolytic treatment had a strong and immediate effect, and almost no odour was noticeable. Aeration also reduced hydrogen sulphide emission from about 2000 p.p.m. in the raw slurry to about 300 p.p.m. Additional electrolytic treatment immediately reduced this level to about 150 p.p.m. and further to zero after 10 weeks.

Only 0·13% of total-N was lost from the aerobic reactor, and this amount was absorbed by a biofilter. After 45 weeks storage the amount of ammonium-N was equal in raw, aerated, and combined aerated and electrolysed slurries. During the electrolytic treatment the Cu content in the slurry increased from 20 mg/kg TS to about 300 during the first ten weeks, by which time all the desired treatment effects had been obtained.

Long-term storage of raw cattle slurry did not solve the odour and hydrogen sulphide problems, but pathogen kill was effective. Aerobic treatment in a reactor produced a slurry with practically no TCB, low odour level and low hydrogen sulphide emission, without losing nitrogen. The aerated slurry was suitable for long-term storage. Additional electrolytic treatment of the aerated cattle slurry further reduced the pathogen, odour and hydrogen sulphide concentrations. By combining aerobic and electrolytic treatment it was possible to achieve full control of pathogen bacteria, odour and hydrogen sulphide.

1. Introduction

Handling and use of raw cattle liquid manure can cause environmental and health problems. Pathogen control is of importance in protecting fresh water sources. For example, application of raw, liquid manure to farm land is forbidden in water-protection areas in Baden-Württemberg, Germany, due to the risk of contaminating drinking water.[1] Also to avoid the spreading of animal diseases, pathogen control is of importance, e.g. to control the parasite causing Cryptosporidiosis disease, aerobic treatment of infected faeces is recommended in Scotland.[2] Pathogen control is particularly necessary if slurry from several farms is handled, stored or applied mutually.

To protect the atmosphere, great efforts are being made in several countries to control the ammonia emission from slurry. Unpleasant odour from processing, storing and application of livestock slurry is a cause of complaint from people living in livestock regions. Farmers need to make efforts to rectify this situation.

Liquid manure releases the toxic gas hydrogen sulphide when pumped or mixed. Several tragic accidents and fatalities have occurred, and continue to occur, due to over exposure to this gas. This is a particular problem where livestock is confined with slurry stored below the floor of the animal housing.

As the manure usually needs to be stored for relatively long periods before spreading, methods to upgrade its quality, combined with storage, are considered in this paper. The main idea was to test whether a combination of aerobic and electrolytic treatment could give favourable effects. Normally, aerobic treatment in a reactor effectively reduces the pathogens, odour and H_2S emission, but the properties of the aerated slurry after a long storage period have not been tested. Electrolytic treatment is used for reducing the odour from slurry. Would the electrolytic treatment guarantee or improve the quality of slurry obtained from one week of aeration after storage for about one year? If so, these two treatment methods would complement each other.

The object of the study was to compare the upgrading and subsequent storage of liquid cattle manure following two different treatments of the raw slurry. The three conditions examined were:

(1) long-term storage of raw slurry;
(2) thermophilic aeration in a reactor followed by long-term storage; and
(3) thermophilic aeration in a reactor and electrolytic treatment during subsequent long-term storage.

The study focused on chemical and physical characteristic, hygienic quality, odour production, release of toxic and greenhouse gases and layer formations (for example, crusting and sedimentation).

2. State of the art

2.1. *Long-term storage*

Long-term storage can lead to stabilization of organic matter. If the storage period exceeds 6 months, odour is reduced and the hygienic quality is improved.[3] These processes are strongly affected by temperature and total and volatile solids content in the slurry. The main reason for storing the slurry is to avoid water pollution caused by its application to farm land during periods of the year when the crop uptake of nutrients is low. Storing is also recommended by European legislation as the minimum treatment required to upgrade the slurry.[4]

2.2. *Thermophilic aeration (liquid composting) in a reactor*

Thermophilic aeration turns organic waste into a stabilized and hygienic product. It requires a supply of air for the aerobic bacteria to break down the organic material into simpler compounds. This process releases a considerable amount of heat which raises the temperature of the reactor contents.

Oechsner[5] investigated double reactors for aeration in two steps using spiral aerators to attempt pathogen reduction in cattle and pig slurry. The temperature levels obtained in the reactors were sufficient for decreasing the content of Salmonella bacteria to zero.

Svoboda[6] investigated aerobic treatment of pig slurry in an insulated 23 m^3 reactor with a surface aerator. High nitrogen losses, $> 50\%$, were observed at temperatures around 36°C and 10 d retention time. The pathogens and odour were effectively reduced, and the compost heat was utilized for heating the piggery.

Results presented by Skjelhaugen[7,8] were based on a novel aerator specially designed to fit into an insulated reactor for thermophilic treatment. The process parameters were optimized for conserving the ammonia in the slurry and minimizing the energy consumption. In the trials, the slurry was areated without losing ammonia and without releasing odours.

Norin[9] obtained successful control of pathogens in a laboratory-scale aerobic reactor. He also obtained full control of ammonia and odour release. His investigations are partly based on the results from Skjelhaugen and Sæther.[10]

2.3. *Electrolytic treatment*

The electrolytic treatment is based on oligodynamic action, where small quantities of metal ions dissolved through electrolysis, sterilize some microorganisms. The treatment takes place in the storage tank and lasts for several months (*Fig. 1*). Although the electrolytic process is not completely understood, the effect is believed to be based on the following actions:[11,12]

(1) *Oligodynamic action*: Dissolved copper ions reduce the fermentation and/or respiratory activities of the microorganisms in the slurry.
(2) *Binding action*: The odorous compounds can be bound by the dissolved copper ions.
(3) *Electric action*: Fermentative and respiratory activities of the microorganisms in the slurry are reduced by means of electric current that can affect cellular membrane mechanisms and ATP (adenosine 5-triphosphate) synthesis.
(4) *Anti-flocculation action*: The electric field in the slurry and the gas production at the electrodes affect the raw solids and the crust production, so that layer formation can be controlled.

The electrolytic treatment unit applied to livestock slurries creates an electric potential between 1 and 5 V and a current of 0·5 and 1·5 A between two copper

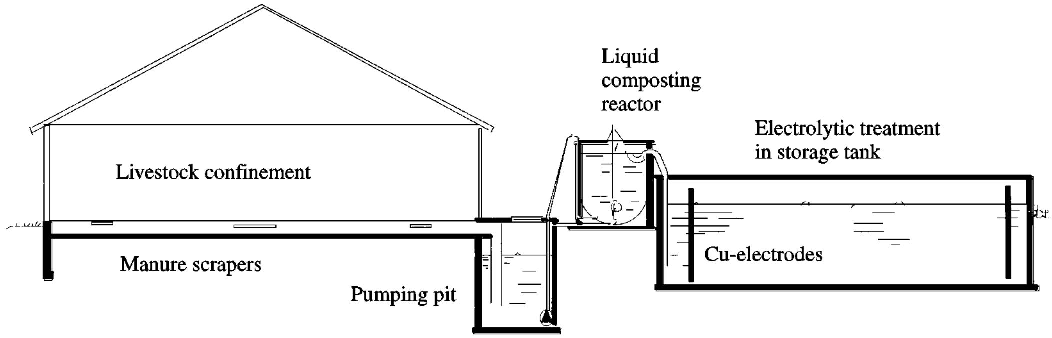

Fig. 1. Combined aerobic and electrolytic treatment of livestock slurry

electrodes. One pair of electrodes serves up to 500 m^3 of slurry. The power required is 50 W per pair of electrodes, and the energy consumption ranges from 2·5 to 3·5 Wh/m^3 slurry when treated over 4 to 6 months. One week before spreading, the dissolved copper ions can be partially collected by replacing the copper electrodes with iron ones.[13]

The electrolytic treatment applied to the livestock facilities in Italy proved capable of controlling the release of odorous compounds during both storage and spreading operations. The control of odour release appears particularly necessary for livestock buildings where manure is stored beneath the slatted floor.

3. Materials and methods

Three concrete tanks, located at the Agricultural University of Norway, were used (*Fig. 2*). The tanks were identical, covered, cylindrical and partly beneath the ground level, with a volume of 60 m^3 (3 m deep, 5 m diameter). The tanks were filled over four weeks; tank 1 with 30 m^3 untreated slurry, tanks 2 and 3 with 30 m^3 aerated slurry in each. The storage period lasted 45 weeks, during which the electrolytic treatment of the aerated slurry in tank 3 took place. The slurry came from a dairy cow barn with sawdust used as litter for the stalls.

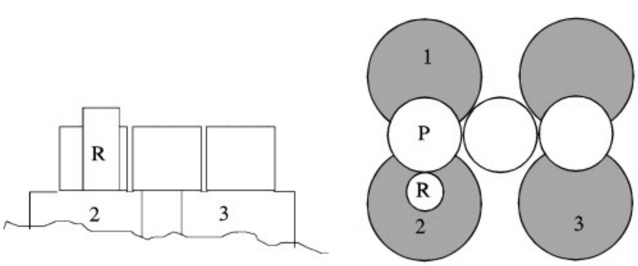

Fig. 2. Layout of the research plant: 1 covered tank for raw slurry; P pumping pit; R liquid composting reactor; 2 covered tank for aerated slurry from the reactor; 3 covered tank for aerated slurry from the reactor, electrolysed during storage period

3.1. *Reactor aeration*

The aerated slurry was produced by means of an insulated, 10 m^3 vertical reactor as shown in *Fig. 3*. The reactor was circular in shape with a conical bottom especially designed to accommodate a unique submerged aerator. Atmospheric air was bubbled into the biomass by the aerator. Details related to the aerator design and to the biomass flow pattern were critical for obtaining good processing results.[7,8]

The continuous composting of the cattle slurry was accomplished according to the parameters given in Table 1. The daily slurry exchange procedure involved stopping the aerator and pumping cold raw slurry into the bottom of the reactor, which caused warm slurry to flow to the storage tanks 2 and 3 through an overflow at the top. Aerobic treatment of all the slurry required for this experiment took four weeks, after a two week starting period. A biofilter was used to reduce airborne pollutant emissions from the process.

One of the most interesting features of the process was the high oxygen utilization of about 95%. This explains the low air flow needed for the aeration and the low amount of ammonia released from the biomass.[10] The reactor produced neither unpleasant odours nor ammonia loss to the atmosphere.

3.2. *Electrolytic treatment*

The equipment for electrolytic treatment installed in tank 3 is shown schematically in *Fig. 4*. Two copper electrodes, each 1 m long, were suspended in the slurry 0·1 m above the bottom. The polarity of the electrodes was switched regularly in order to reduce the average resistance in the slurry. After 8 months the copper electrodes were replaced by iron electrodes. This led to the replacement of copper cations in the slurry with iron cations. The operating parameters are shown in Table 2.

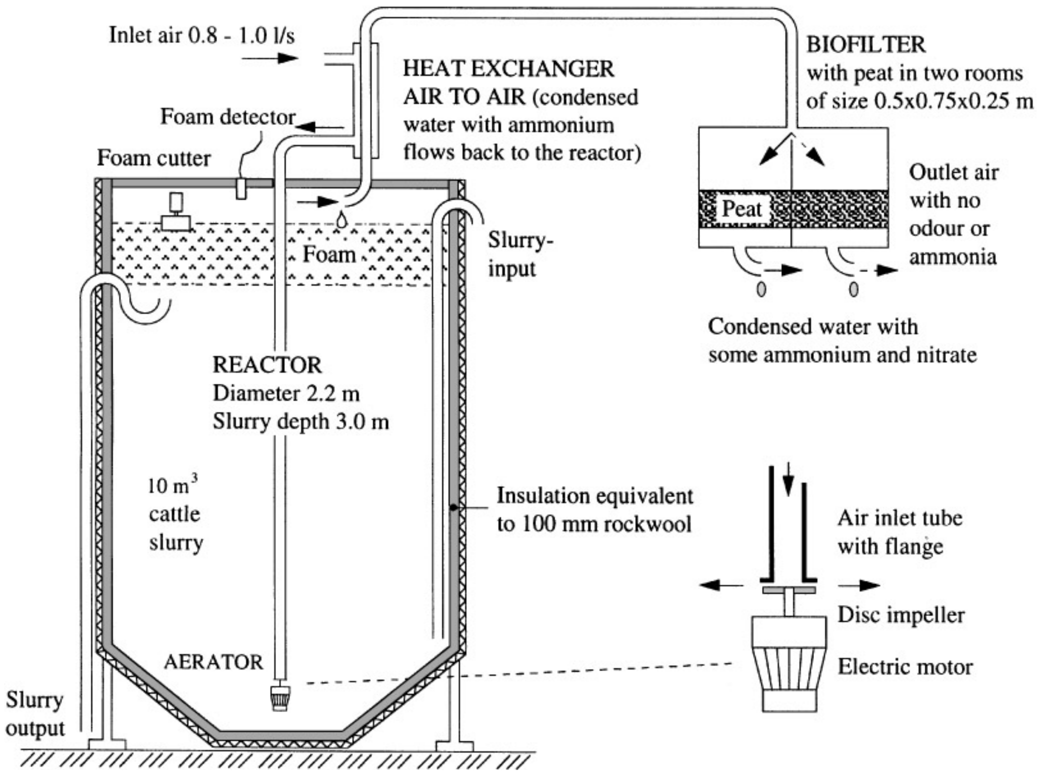

Fig. 3. Liquid composting reactor for the continuous processing of organic liquid waste to a hygienic and stabilized slurry

3.3. *Sampling*

During the treatment and the 45 week storage period, samples were taken of the slurry, odour and gas emissions. For slurry sampling, a sampler was used which consisted of a 50 mm diameter and 4 m long tube with a valve at the bottom end. The volume of each subsample was 3 l. From three subsamples, 9 l sample was obtained, and 0·5 l of this was sent to the laboratory for analysis. The sampler was opened, submerged to the bottom of the slurry and then closed for an average sample of the total store contents. For samples at specific depths the sampler was closed and submerged to the required depth, opened and then closed again.

The following parameters were determined from the liquid composting reactor and the tanks 1, 2 and 3.

Table 1
Parameters related to continuous treatment in the liquid composting reactor

Period of treatment	4 weeks, October 1991
Treatment capacity	1·5–2·0 m^3/d
Retention time	4–7 d
Reaction temperature	48–55°C
Air input	4 kg/h
Oxygen utilization	$>95\%$
Oxygenation capacity	0·8 kg O_2/h
Dissolved oxygen (DO) in the biomass	$<0·1$ p.p.m.
Specific power	190 W/m^3 reactor volume
Energy consumption	26 kWh/m^3 treated slurry
Aeration efficiency	0·4 kg O_2/kWh
Ammonia loss from the reactor (absorbed by the biofilter)	0·13% of total-N

(1) Total and volatile solids were measured by drying the samples for 24 h at 104 and 600°C, respectively.

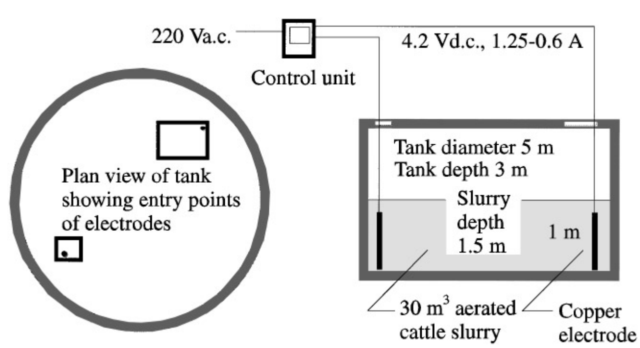

Fig. 4. The electrolytic treatment system used in the trials

Table 2
Parameters related to the electrolytic treatment of reactor composted slurry

Period of treatment		33 weeks, November 91–June 92
Amount of treated slurry		30 m^3
Depth of slurry in the storage tank		1·5 m
Number of copper electrode pairs		1
Voltage		4·2 V
Current intensity	Weeks 0–7	1·25 A
	Weeks 8–33	0·50 A
Polarity change frequency		Six times per hour
Energy consumption		8 kWh/m^3 treated slurry

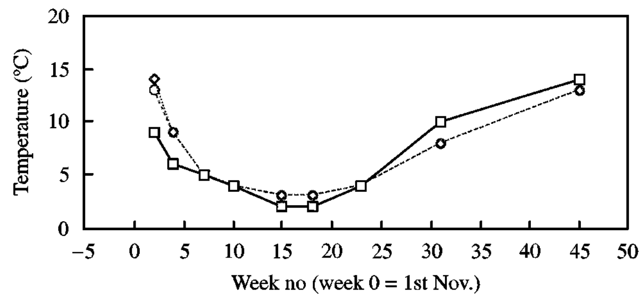

Fig. 5. Slurry temperature in the stores subjected to different treatments: —□— Stored raw slurry; ·····◇····· Stored aerated slurry; ----○---- Aerated slurry electrolysed during storage

(2) pH was measured with a "Digi Sense pH meter", model 5985–40.
(3) Total and ammonium-nitrogen, copper, chemical oxygen demand and volatile fatty acids were measured by using standard APHA, AWWA, WPCF method.[14]
(4) Temperatures were measured every 2 h with a data logger connected to copper-constantan wires placed 0·1, 0·6 and 1·2 m above the bottom.
(5) Pathogen levels were indicated by counting thermotolerant coliforms using standard APHA, AWWA, WPCF method.[14]
(6) Odour from the slurry was measured using an olfactometer.[15] One person sampled a tube of fresh air with air bubbled through a slurry sample. The dilution ratio, that is, the ratio of fresh to odours air which gave a noticeable odour was identified.
(7) Ammonia and hydrogen sulphide emissions from the slurry were sampled by shaking a 20 l can three-quarter filled with slurry for 1 min and measuring the gas concentrations using a Dräger hand pump.
(8) Methane, carbon dioxide and nitrous oxide concentrations in the closed stores were sampled by sucking the gas out with a syringe, injecting it into a vacuum sampling bottle and analysing it by gas chromatography. The sampling point was 50 mm above the slurry level in the tanks.

4. Results

4.1. *Characteristics of the slurry*

The 45 week storage period included all seasons of the year in a Nordic climate. The difference between slurry temperatures during the first few weeks was caused by the warm slurry from the reactor (*Fig. 5*). In tanks 2 and 3 the temperatures were equal during the whole period. Temperature differences might therefore be excluded when discussing the results. For most of the period, the low temperatures caused by the surroundings indicate low microbiological activity.

The characteristics of the raw slurry, the aerated slurry and the slurry stored under different conditions are given in Table 3. The ratio of volatile volids to total tolids was

Table 3
Characteristics of the raw, aerated and stored slurries

	Type of slurry				
Parameter	*Raw*	*Reactor output*	*Raw, stored 45 weeks, tank 1*	*Aerated and stored 45 weeks, tank 2*	*Aerated and electrolysed 45 weeks, tank 3*
TS, %	7·5	6·4	6·4	6·3	6·2
VS, % of TS	86	84	84	83	80
COD, g/l	~ 55	~ 40	~ 40 (w.23)	~ 35 (w.23)	~ 35 (w.23)
pH	6·8	8·0	7·7	7·9	7·8
Tot-N, g/kg TS	29	29	26	25	24
NH_4-N, g/kg TS	15	15	13	13	13
Cu, mg/kg TS	21	n.m.	n.m.	n.m.	335

w. = week; n.m. = not measured; TS = total solids; VS = volatile solids; Tot-N = total nitrogen; NH_4-N = ammonium nitrogen; Cu = copper.

high (84%), and little affected by the aerobic treatment due to the short retention time. The pH level increased during composting, from 6·8 up to 8·0, and decreased slightly during storage. There was no significant difference between the slurry types after a storage period of 45 weeks. No nitrogen was lost during composting in the reactor. There were no significant differences between nitrogen losses during the storage period from the three slurries (10–17%). There was also no significant difference between the NH_4-N content after the storage period (about 13% loss). COD reduction was moderate, due to limited aeration. The object was to obtain a stable slurry, and not to achieve maximum COD reduction.

The copper content in the raw slurry was about 20 mg/kg TS. Due to the use of copper electrodes in the electrolytic treatment, copper was dissolved in the slurry. The content increased to about 300 mg/kg TS during the first ten weeks. At this point the current was reduced and the increase stopped (*Fig. 6*). At the end of the electrolytic treatment, week 33, the copper electrodes were replaced by iron electrodes. The electricity was controlled in a specific way to attempt replacement of most of the copper cations with iron cations.[13] This, however, was not successful, and the copper content was roughly the same after a 10 d attempted replacement period. The process was probably inhibited by the relatively high solid contents of the slurry.

4.2. *Hygienic quality*

The content of thermotolerant coliform bacteria (TCB) is often used to indicate the content of other pathogenic bacteria. A content lower than 2500 per gram total solids is normally considered to be an acceptable level. Converted to approximately 6% TS, i.e. the TS content of the slurry used in these trials, the maximum acceptable density is about 150 TCB/g of slurry. Table 4 shows the reduction of these bacteria during the different treatments and storage methods. Compared with the initial raw slurry, bacterial numbers were considerably reduced.

Table 4
Content of thermotolerant coliform bacteria (TCB), numbers per gram of slurry

Storage period (weeks)	*Type of slurry* Raw, in tank 1	Reactor output	Aerated in tank 2	Aerated and electrolysed, in tank 3
− 2	$1{\cdot}7 \times 10^4$	$< 10^2$		
− 1	$1{\cdot}0 \times 10^4$	$< 10^2$	$3{\cdot}5 \times 10^2$	
0	$1{\cdot}0 \times 10^4$	$< 10^2$	$< 10^2$	$< 10^2$
2	$1{\cdot}6 \times 10^3$		$2{\cdot}0 \times 10^2$	$< 10^2$
4	$1{\cdot}5 \times 10^3$		$4{\cdot}0 \times 10^2$	$< 10^2$
10 − 18			$< 10^2$	$< 10^2$
23	$< 10^2$		$< 10^2$	$< 10^2$
45	$< 10^2$		$< 10^2$	$< 10^2$

Negative weeks are weeks when aerated slurry was produced in the reactor, week 0 = start of storage period and electrolytic treatment.

4.3. *Odours*

The odour from the raw slurry was unpleasant during the whole storage period. Odour from the aerated slurry was noticeable, but not unpleasant. It varied during the storage period and had a different character to that of the raw slurry. *Figure 7* shows the trends in odour production during the trial period. The aerated and electrolysed slurry released significantly lower odour levels than the other slurries, and almost no odour was noticeable. The hydrogen sulphide levels (*Fig. 8*) corresponded well with the odour levels, as this gas contributes strongly to odour production. Also the VFA level in the slurry partly corresponded to the odour production. According to Table 5,

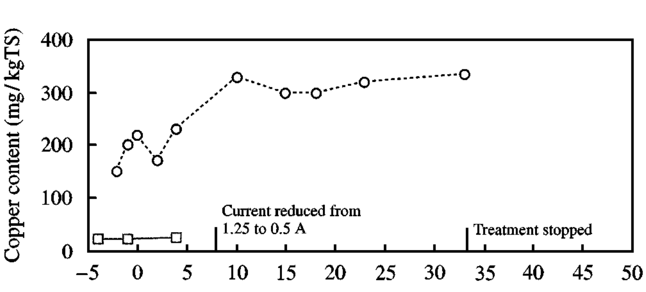

Fig. 6. Copper content in the slurry (reabsorption not accomplished): —□— Stored raw slurry; ----○---- Aerated slurry electrolysed during storage

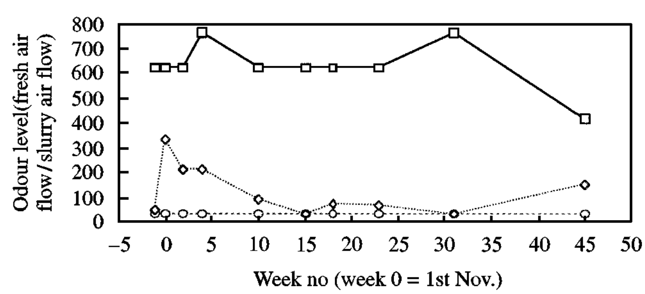

Fig. 7. Odour from the slurry given as the inverse ratio between the airflow from the slurry samples and the flow of fresh air at the point at which odour was first noticed by a panel: —□— Stored raw slurry; ·······◇······· Stored aerated slurry; ----○---- Aerated slurry electrolysed during storage

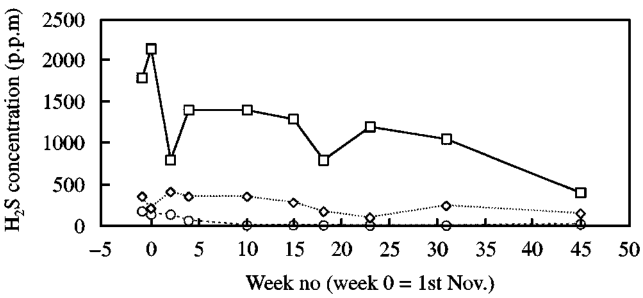

Fig. 8. Hydrogen sulphide (H_2S) concentrations at the slurry sample surface after shaking: —□— Stored raw slurry; ⋯◇⋯ Stored aerated slurry; ----○---- Aerated slurry electrolysed during storage

the VFA level was reduced by 20–50% during the thermophilic 7 d aerobic treatment in the reactor. Further reduction was not achieved by the electrolytic treatment. A small reduction was seen as a result of the long-term storage of the raw slurry.

4.4. *Ammonia and hydrogen sulphide emissions*

Ammonia emission was low, below 5 p.p.m. for the entire 45 weeks for all types of slurry. Hydrogen sulphide emissions (*Fig. 8*) from the raw slurry caused concentrations of around 1400 p.p.m. in the air above the slurry surface during the first 15 weeks, decreasing to about 1000 p.p.m. after 30 weeks. The aerated slurry caused concentrations of about 300 p.p.m. during the first 15 weeks, decreasing to about 150 p.p.m. after 46 weeks. The aerated and electrolysed slurry lead to air concentrations of about 150 p.p.m. of hydrogen sulphide during the first 4 weeks after which it decreased to, and remained at, almost zero for the rest of the 46 week storage period.

Table 5
The content of volatile fatty acids (VFA) in the slurry

		Type of slurry		
VFA	*Week no*	*Raw, in tank 1*	*Aerated, in tank 2*	*Aerated and electrolysed, in tank 3*
Butyric acid, g/l	0	2·0	1·0	1·0
	10	1·5	0·8	0·8
Propionic acid, g/l	0	1·8	1·0	1·0
	10	1·3	1·0	1·0
Acetic acid, g/l	0	4·0	3·2	3·2
	10	4·0	3·2	3·2

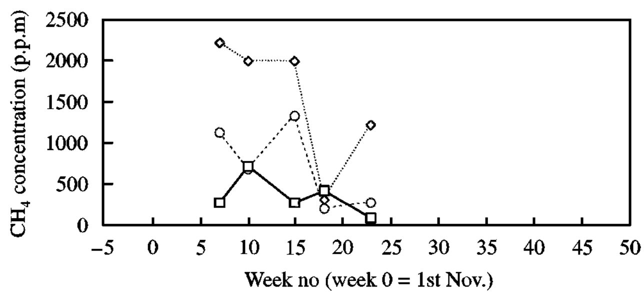

Fig. 9. Methane (CH_4) concentrations in the three covered storage tanks: —□— Stored raw slurry; ⋯◇⋯ Stored aerated slurry; ----○---- Aerated slurry electrolysed during storage

4.5. *Greenhouse gases*

Raw slurry produced small amounts of methane thoughout the trial period (*Fig. 9*). Aerated slurry produced amounts four to five times higher until week 15, thereafter the concentrations were almost the same as from the raw slurry. It appears that the aerobic treatment improved the conditions for methane production in the first part of the storage period. Presumably, the result is a temperature effect, even if the temperature was similar after week 7. Gas produced in the closed storage tanks did not disappear until week 15. The electrolytic treatment lead to an immediate halving of the methane production potential from the aerated slurry. Presumably, this was because it hampered the microbiological activity.

The result for carbon dioxide (*Fig. 10*) are similar to the methane production results mentioned above. This is reasonable since these gases are the main constituents in biogas, which is produced in small amounts under anaerobic conditions during storage.

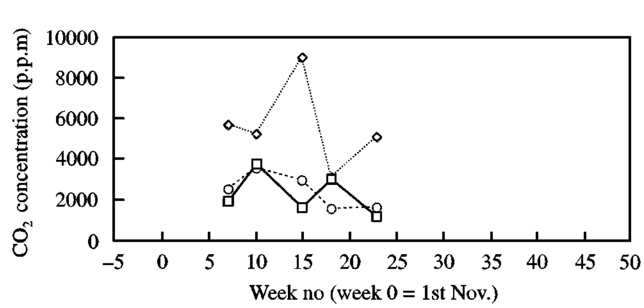

Fig. 10. Carbon dioxide (CO_2) concentrations in the three covered storage tanks: —□— Stored raw slurry; ⋯◇⋯ Stored aerated slurry; ----○---- Aerated slurry electrolysed during storage

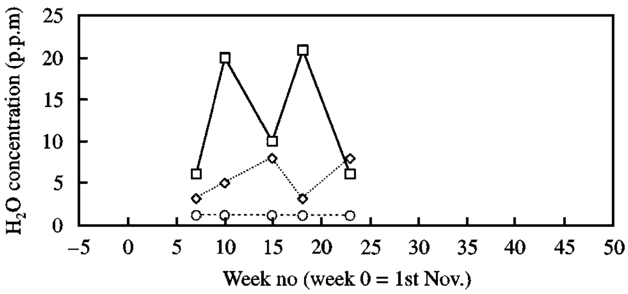

Fig. 11. Nitrous oxide (N_2O) concentrations in the three covered storage tanks: —□— Stored raw slurry; ···◇··· Stored aerated slurry; ---○--- Aerated slurry electrolysed during storage

Raw slurry produced the largest amounts of nitrous oxide (*Fig. 11*). Aerated slurry produced considerably lower amounts. The electrolytic treatment reduced the nitrous oxide production to almost zero.

4.6. *Layer formations*

Crust formation was only found in the raw slurry (Table 6). The degree of sedimentation was less in the treated slurries than in the raw slurry. The electrolytic treatment tended to reduce the TS content in the sediment in the aerated slurry, but only small differences were found.

4.7. *Energy consumption*

The energy consumption for the combined treatment was 33·2 kWh/m^3, and 78%, or 26 kWh/m^3, was consumed by the aeration alone. The figures are high due to the small volumes treated, the relatively high TS content and the intensive aeration.

Table 6
Layer formations in the slurry

		Type of slurry		
Layer formation	*Week no.*	*Raw, in tank 1*	*Aerated, in tank 2*	*Aerated and electrolysed, in tank 3*
Crust formation	45	Yes	No	No
Sediment formation, % of slurry depth	31	50	35	35
TS content of sediment, %	31	8–9	9–10	8–9

5. Discussion

5.1. *Pathogens*

The pathogen control in the aerobic reactor, indicated by the thermotolerant coliform bacteria content, was effective. Similar results were found by Oechsner[5] and Norin[9] who also made trials in insulated reactors. The storage tanks for the aerated slurry were not well cleaned beforehand, and some samples showed TCB contents between 200 and 400 per gram of slurry during the first month. However, electrolytic treatment decreased the content very quickly. The figures for the raw slurry were high during the first storage period, but below 100 after 23 weeks. This indicates that long-term storage is an effective method for pathogen control.

One question of special interest was if the slurry output from the reactor could be stored for a long period without incuring a new growth of TCB. The results indicate that the answer is yes. In addition, the aerated cattle slurry was suitable for electrolytic treatment which can help in controlling the renewed pathogen growth during storage.

5.2. *Ammonia*

The process control in the reactor prevented loss of nitrogen during aeration. The high oxygen utilization, $>95\%$, strongly reduced the airflow through the slurry, and hence also the ammonia loss. It should be noted that the normal oxygen utilization for submerged aerators is between 20 and 40%. The peat biofilter for cleaning the exhaust air from the reactor had minor importance, as the ammonia loss from the reactor itself was only 0·13% of total-N, measured before the filter. In addition, the well dispersed and optimal dissolved oxygen content in the slurry, resulted in low NH_3 release from microbiological activity during the 7 d hydraulic retention time.[16] Cumby[17] confirms that above 50°C almost all nitrification ceases, and more of the fertilizer value of the slurry is therefore retained.

The equal ammonium content in the three slurry types when stored for ten months, and the low ammonia release from the slurry during storage, indicates that neither treatment before nor during the storage period had an influence on the ammonia release.

5.3. *Odour*

Long-term storage of raw slurry did not reduce the odour to an acceptable level. On the other hand, aeration stabilized the slurry and so rendered it acceptable for at least 10 months without further treatment. There was, however, biological activity in the slurry that continued to produce small amounts of odours and gaseous emissions. If a very low emission level is to be guaranteed, the retention time during the aeration process must be increased. The electrolytic treatment effectively decreased odour production to a non-detectable level. This was noticed from the very beginning of the treatment period. Obviously, aerated cattle slurry is well suited for electrolytic treatment.

The VFA figures correspond with the results from the odour panel in the main, but they do not explain why the electrolytic treatment could achieve such low odour levels. The reduced microbiological activity in electrolytically treated slurry, as evidenced by reduced H_2S production, may provide an explanation.

5.4. *Hydrogen sulphide*

Aeration strongly reduced the hydrogen sulphide release from the slurry, and the electrolytic treatment further reduced it to zero during the first 4 weeks. Compared with raw slurry, which released concentrations at a highly dangerous level, the results are very positive. The two treatment methods had separate effects on the H_2S emission. In this investigation, aerobic treatment reduced it by about 80%. According to tests carried out by Chiumenti and Donantoni,[18] electrolytic treatment reduced H_2S emission from cattle slurry by 30–40%. The combined aerobic and electrolytic treatment totally eliminated H_2S production from the aerated cattle slurry, and thereby also the safety risk arising from this gas during pumping, mixing and spreading. In addition, as H_2S forms a major part of the odorous compounds, unpleasant odour was eliminated.

5.5. *Microbiological activity*

Production of methane, carbon dioxide and nitrous oxide is related to the anaerobic activity in the slurry. The activity was highest in the aerated slurry, and the electrolytic treatment reduced it to a low level. This indicates that the impact of the treatment on odour, hydrogen sulphide and pathogens is caused by an effective microbiological control. The copper cations dissolved in the slurry inhibited the activity of the anaerobic bacteria.

5.6. *Copper from the electrolytic treatment*

The use of a standard “Oligomat” treatment unit in a relatively small volume of slurry caused a strong dissolution of copper. There is a limit to the amount of copper which can be spread onto agricultural land. The maximum permissible amount is 600 mg/kg TS.[19] The electrolysed slurry had a copper content below this limit, but it was also significantly greater than that in untreated manure. It appears that similar results could be achieved with lower copper concentrations, by improved operating conditions. This could include increasing the frequency of polarity change and reducing the average voltage (Müller, unpublished data). On the other hand, Donantoni and Soriato[20] have shown that the voltage must exceed a certain minimum level (1·5–2·5 V), in order to guarantee copper dissolution. Also reduced treatment time will reduce the copper content. The maximum effect was obtained after 4 to 5 weeks, and the treatment could have been stopped at that time.

5.7. *Layer formations*

No crust was formed during ten months of storage in the aerated and in the combined treated slurry. However, crust did form in the raw slurry. Some local crust was formed around the copper electrodes, which caused no practical problems. Also sedimentation was found to be less compared with the raw slurry. Neither the aerobic nor the electrolytic treatment seemed to cause any practical slurry handling problems. Norin[9] treated municipal waste, and a mixture of municipal waste and livestock slurry, in a small scale, thermophilic, aerobic reactor. He found that the treatment decreased crust formation and increased sedimentation during storage. The reduced layer formation is due to microbiological and mechanical degradation of the crust forming particles, as well as effective homogenization during the aeration.

5.8. *Transfer value of the results*

The volume and capacity of the liquid composting reactor is similar to commercial reactors, and comparable results are obtained when processing organic materials other than liquid manure.[10]

Concerning electrolytic treatment, the results presented were obtained using relatively small volumes of slurry. The same results may not be obtained if larger volumes are processed. Chiumenti and Donantoni[18] found that uneven distribution of copper ions in larger volumes reduced the effectiveness of the electrolysis. The characteristics of the slurry are important for successful electrolytic treatment, and results obtained with aerated slurry may not be transferable directly to raw slurry.

6. Conclusions

The content of thermotolerant coliform bacteria (TCB) was reduced from 10^4 TCB/g of slurry to below 10^2 during the 7 d treatment in the aerobic reactor. No new TCB growth occurred during the following 45 week storage period. The electrolytic treatment seemed to ensure an effective pathogen kill. Also raw slurry achieved $< 10^2$ TCB/g after 23 weeks storage.

Due to high oxygen utilization of 95%, low airflow, retention time limited to 7 d and dissolved oxygen concentration below 0·1 ppm in the biomass, only 0·13% of total-N was lost from the aerobic reactor as ammonia. This amount was absorbed by a biofilter, and did not pollute the atmosphere. After 45 weeks storage, the amount of ammonium-N was the same in raw, aerated and combined aerated and electrolyzed slurries.

Aerobic treatment reduced the odour considerably compared with raw slurry. Additional electrolytic treatment had a strong and immediate effect, and almost no odour was noticeable after the combined treatment.

Aerobic treatment reduced hydrogen sulphide emission from about 2000 p.p.m. in the raw slurry to about 300 p.p.m. Additional electrolytic treatment reduced it immediately to about 150 p.p.m. and further to zero after 10 weeks. Combined treatment obviously controls the H_2S problem very effectively.

The disadvantage of electrolytic treatment based on copper electrodes is the increased copper content in the slurry. In this trial it increased from 20 mg/kg TS to about 300 mg/kg TS during the first ten weeks. The electrolytic treatment could have been stopped earlier, when all objectives had been achieved. The copper content can be reduced by reducing the treatment intensity and duration.

When comparing the three conditions examined, we find that long-term storage of raw cattle slurry did not solve the odour and hydrogen sulphide problems. However, the pathogen kill was effective. Four to seven days aerobic treatment in a reactor produced a slurry with practically no TCB, low odour level and low hydrogen sulphide emission. This was achieved without losing nitrogen, a common aeration problem. The aerated slurry was suitable for long-term storage of at least 45 weeks. Additional electrolytic treatment of the aerated cattle slurry enabled full control of pathogen bacteria, odour and hydrogen sulphide to be achieved.

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