NATURAL CRUSTING OF SLURRY STORAGE AS AN ABATEMENT MEASURE FOR AMMONIA EMISSIONS ON DAIRY FARMS

K. Smith[1], S. Brookman[2], T. Cumby[3], J. Lapworth[1], T. Misselbrook[1], E. Nigro[3], A. Williams[3]
[1]ADAS, Woodthorne, Wergs Road, Wolverhampton, WV6 8TQ, UK. ken.smith@adas.co.uk
[2]Institute of Grassland and Environmental Research, North Wyke, Okehampton,
Devon EX20 2SB. UK.
[3]Silsoe Research Institute, Wrest Park, Silsoe, Bedfordshire MK45 4HS, UK

ABSTRACT

Research on the incidence and effectiveness of natural crusting on slurry storage as a means of ammonia emission abatement was undertaken in studies at farm-scale, pilot-scale and on a small-scale. At the farm scale, slurry crusting was found to be commonplace across a large proportion (80%) of slurry storage facilities. Observations provided information on the impact of a range of factors on the potential for crust formation. The most important factors were slurry solids content (crusting increasing with DM content), volume:surface area ratio of the storage (influencing nature of the crust and rate of formation), livestock diet (crusting more likely with grass silage), slurry management (agitation) and, of particular importance, weather conditions with evaporation and rainfall acting on slurry crusts in opposing ways.

From measurements at farm and pilot scale, mean ammonia emissions were 0.48 gNH_3-N $m^{-2}d^{-1}$ and 2.55 gNH_3-N $m^{-2}d^{-1}$, for crusted and non-crusted slurry stores, respectively. Where direct comparisons between crusted and non-crusted slurry were possible, a reduction in NH_3 emission of about 50% was typical during the measurement period. The results reported here have confirmed the potential for significant abatement but need to be demonstrated more consistently under practical farm conditions. The work has also identified potential for a modelling approach for the prediction of crust development and, hence, likely emission abatement efficiency.

INTRODUCTION

There are international pressures to reduce ammonia emissions from agriculture, as transboundary transport and subsequent deposition can damage fragile ecosystems. Manure storage is known to represent an important source of gaseous emissions from agriculture, including ammonia and methane. Pain et al., (2000) estimated that manure storage was responsible for about 5% of total NH_3-N emissions in the UK, with cattle manure storage emissions alone, estimated at 11kt/year and pig manure storage 1.6kt/year. The exposed surface area of stored manure is thought to have an important impact on NH_3-N emissions (Sommer et al., 1993); storage method, physical form of the stored manure and source of manure (livestock type) are also likely to affect emission rates. Slurry crusting affects the exposure of liquid manure surfaces and has been shown to be effective in reducing NH_3-N emissions from stored slurry. Sommer et al., 1993, found slurry crusts as effective as a number of other artificial covers, reducing emissions by as much as 80%.

Whilst a number of low-cost covers have been considered, these appear to be too expensive for farmers to recoup the costs through the value of retained ammoniacal N (Williams, 1998). Natural crusts in slurry stores appear to have significant potential for reducing NH_3-N emissions and so it is important that this simple strategy should be investigated and evaluated. Work within the project was necessarily restricted to cattle slurry, in which surface crusting is commonplace, whereas crusts are rarely seen in pig slurry.

MATERIALS AND METHODS

The research involved on-farm, small-scale and pilot-scale studies.

On-farm studies. A questionnaire was used to collect information on slurry crusting, livestock and store management on a sample of 50 dairy farms chosen to be representative of some of the major dairying areas in England. Further visits were later undertaken to a limited sample of farms where crusting of the store was commonly anticipated. A hydraulically-operated inspection platform, with purpose-built safety cage (EPL, Aston, Birmingham), was hired to allow safe inspection, sampling and assessment of the surface crust on at least two occasions during the storage season (Fig 1a).

A prototype tool for assessment of crust thickness was developed. The device consisted of a rigid plastic tube and nipple for attachment of an inflatable rubber sack (balloon). The rigid plastic tube was inserted through a pre-drilled hole in the crust and the rubber sack inflated below the crust, allowing the distance between the shoulders of the inflated part and the crust surface to be measured. A hand-held penetrometer (Farnell, Hatfield, Herts), modified by the use of a circular metal disc (c.30 cm^2) to replace the standard cone, was used to measure the penetration resistance of the crust (force-plate penetrometer). On some visits vented cover-boxes (SRI) were used to measure ammonia emissions from the surface of the stores. Two cover-boxes were employed simultaneously, allowing a comparison of emissions from disturbed and undisturbed crust. Samples of crust and slurry from the stores were analysed for dry matter (DM), pH, total N, organic carbon and total ammoniacal N (TAN).

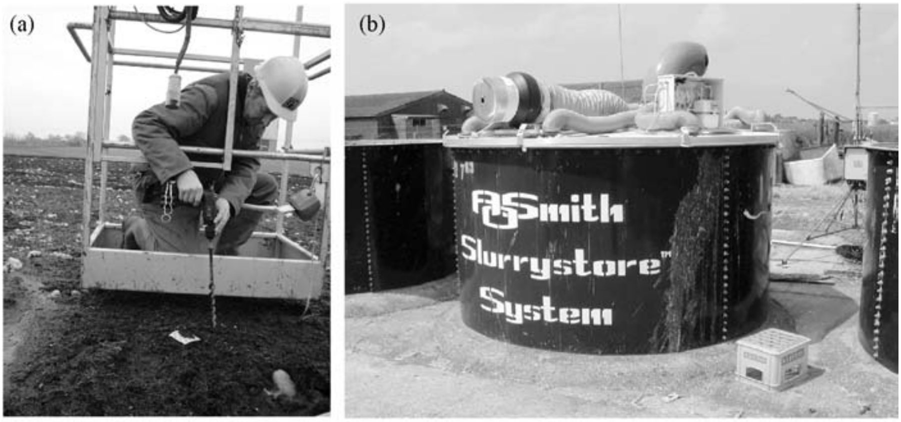

***Figure 1**. Measurements and assessments on slurry stores; (a) inspection platform used on farm stores (b) ammonia extraction cover on pilot scale tank at SRI.*

Small-scale studies. Circular water cisterns (Plastech, Bradford) were used as small-scale slurry stores. The tanks had a total capacity of approximately 680 l, with a height of 0.75 m and top diameter of 1.06 m. When filled with 500 l slurry, there was a freeboard of 0.12 m between the slurry surface and the top of the tank.

The circular lids supplied with the tanks were modified to form an NH_3 sampling array. A centrally located fan (0.16 m diameter) drew air across the slurry surface through 6 inlet holes (0.03 m diameter) cut at regular intervals around the perimeter of the lid. Acid coated glass wool was placed across the inlet holes to remove any NH_3 from the inlet air. Emission rates were measured over a 2-hour period, generally at weekly intervals. Fans were set to run at 2 ms^{-1} through the central duct, equating to a wind speed across the slurry surface of approximately 0.2

m s^{-1}. Observations of crust formation, thickness and extent were made on a weekly basis for the majority of experiments.

Pilot-scale studies. The experiments at Silsoe Research Institute were completed using a set of ten, circular steel, storage tanks. These enabled detailed observations of slurry crusting and impacting factors (climatic impacts, formation, strength, thickness and resistance to liquid mixing). An adjustable working gantry allowed access to crusted slurries in the tanks with a wide variety of slurry depths to enable strength and depth measurements to be undertaken safely. Ammonia emissions were measured by headspace air extraction from beneath vented lids (Fig 1b). Ambient and exhaust air was sampled for ammonia, with aspirated acid bubblers for typical sampling times of a few hours. Within the ammonia measurements a coefficient of variation (cov) of 15% was achieved.

RESULTS AND DISCUSSION

A slurry crust was found in 39 (78%) of the 50 stores initially inspected. Though crust incidence appeared greater in above ground tanks than in other store types, and in the Midlands and North of England, this is likely to have been coincidental and the result of factors other than store design or climate. Similarly, whilst there appeared to be a trend towards crusting with a grass silage diet compared with maize, there is insufficient evidence for conclusions. There appeared also to be increasing crusting incidence with increasing store volume/surface area ratio, reflecting the hypothesis that greater opportunity for gasification in deep slurry stores is likely to cause greater accumulation of fibre at the slurry surface.

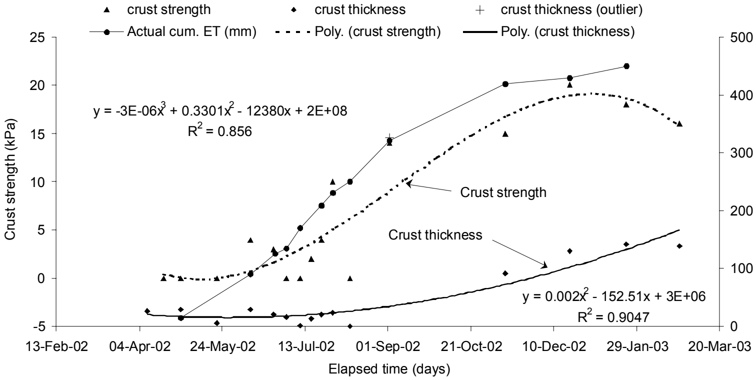

Figure 2. Example of changes in crust thickness and strength with time; pilot-scale studies at SRI.

Ammonia emissions

For those experiments including direct comparisons between crusted and uncrusted slurry (3 small-scale and 7 farm-scale observations), the presence of a crust reduced the mean NH_3 emission rate by c. 50% over the duration of the observations. Sommer *et al.* (1993), using small-scale storage tanks (*c.* 4 m^3), showed a natural crust on cattle slurry reduced emissions to 20% of those from stirred slurry. The reduction in these studies was less, possibly because the non-crusted slurry was not stirred and, in some cases, did develop a thin 'skin'. Mean emission rates from crusted slurries, ranged from 0.5 – 5.9 g N m^{-2} d^{-1}, comparing extremely well with the value in the UK NH_3 emissions inventory for crusted cattle slurry stores of 2.2 g N m^{-2} d^{-1} (range 0.4 – 5.7 g N m^{-2} d^{-1}) (Pain *et al.*, 2000). Emissions for uncrusted slurries were greater, ranging from 1.0 – 13.2 g N m^{-2} d^{-1}. It was considered that the small-scale tanks (c. 1 m^3), whilst satisfactory for comparative studies, would not be representative of real slurry stores and data from those should not be included in inventory EF estimates. Excluding these data, mean EF of 0.48 g NH_3-N m^{-2} d^{-1} and 2.55 g NH_3-N m^{-2} d^{-1} were derived, for crusted and uncrusted slurry stores, respectively.

Factors affecting crust formation

Whilst there was no evidence from the farm studies of a regional trend for crusting and possible climatic effects, detailed pilot-scale observations (summarised in Fig 2) gave strong evidence of a climatic impact. In these observations it was clear that overall increases in crust thickness and strength were matched by the cumulative evaporative water loss from the tank. The studies also provided an indication that robust crusts (i.e. >c.75 mm) are unlikely to form, until at least 250mm of evaporative loss had occurred from the surface of the slurry. The pilot-scale studies also supported the hypothesis that deeper tanks (with increased volume/surface area ratios) would sustain the thickest and strongest crusts, due to the greater availability of crust forming material beneath the exposed surface.

CONCLUSIONS

- About 80% of slurry stores were found to be crusted during an initial study of 50 dairy farms across major dairying areas in England. Regular slurry agitation was carried out by 68% of farms
- Formation of a natural crust on cattle slurry stores reduced NH_3 emission by approximately 50%
- Slurry DM content had an important impact on crust formation – crusts did not form on slurries with a DM content of <1%
- The nature of the DM content may be important – large differences were observed in crust formation on slurries from cattle fed maize or grass silage
- Crust thickness was related to cumulative evaporation of water from the surface of the slurry. Robust crusts (i.e. >75 mm) did not develop until at least 250 mm of evaporative loss had occurred
- Slurry stored in tanks with low volume/surface area ratios tended to produce crusts rapidly, probably as a result of rapid evaporative loss from the slurry surface. Stores with high values of the ratio eventually produced thicker, stronger crusts, although this could take months to occur, perhaps due to slow evaporative loss from the limited surface area

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