Investigating new Markets for Recycled Plasterboard - Odour Control in Scottish Agriculture.

Colin Hunter & Ole Pahl

School of Engineering and Built Environment

Glasgow Caledonian University

70 Cowcaddens Road

Glasgow G4 0BA

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INNOVATIONS FOR SUSTAINABLE BUILDING DESIGN AND REFURBISHMENT

1. INTRODUCTION

The construction industry in the UK is one of the largest industries in the country with an output which is worth more than 100 billion pounds per year. It accounts for 8% of GDP and a total of 3 million jobs. Consuming more than 420 million tonnes of materials a year, it generates around 20% of the countries waste (Department for Business, Enterprise & Regulatory Reform, 2008). Out of the total construction waste, it is estimated that in total more than one million tonnes of plasterboard waste is produced in the UK each year (Waste & Resources Action Programme, 2012). Through the Landfill Directive, the UK government has set a target of 35% of all waste sent to landfill by 2015 from that sent in 1995. Scotland set its own target of 70% recycling of all waste by 2025 (Scottish Government (2010). Thus alternative usage of constructional waste, rather than ending up in landfill, needs to be considered.

1.1 Existing and potential routes for plasterboard reuse.

Currently, recycled plasterboard is approved for use as a feedstock for the manufacture of new gypsum-based products; as a soil treatment agent in agriculture and in the manufacture of cement (Environment Agency, 2011). On average 20% - 25% of new plasterboard can be made up of recycled gypsum without affecting the quality of the final product (Waste & Resources Action Programme (2007a). In addition, the use of recycled gypsum in plasterboard manufacture is dependant on its price per tonne, in Scotland, there are no plasterboard manufacturers and thus recycled gypsum will have to be shipped to producers in the North of England thus transport cost will be a major component of the price potentially making recycling unviable. Plasterboard waste can be used successfully in low-medium strength concrete mixes for the foundations of minor roads and car parks. (Waste & Resources Action Programme, 2007b) In the agricultural and horticultural environment, recycled gypsum has been demonstrated to be an effective soil improver especially for crops such as potatoes (Waste & Resources Action Programme, 2007c) and for use in mushroom compost (Waste & Resources Action Programme, 2007d).

In addition, its use as alternative animal bedding has been suggested (Department for Environment, Food and Rural Affairs, 2008). In the UK, 72% of dairy cattle are housed in a slurry based system; these use cubicles with either scraped passages or slatted floors. Sawdust and shavings is the most common type of bedding in these systems, with rubber mats and chopped straw also being common (Department for Environment, Food and Rural Affairs, 2006). UK dairy farmers use more than 8,700 tonnes of bedding material every day, which over a typical winter amounts to 1.6 million tonnes. In 2007, this was estimated to cost UK farming over £66 million per year (Waste & Resources Action Programme, 2007e). Since then demand for sawdust (and thus the price per tonne) has increased driven by the rise in wood pellets and briquettes production in the UK; the UK Forestry Commission reported a total of 244,000 tons of wood pellets and briquettes were produced in 2011, an increase of 24% on 2010 and twice that of 2009. Since traditionally these products have relied on the availability of sawdust it is clear that as the demand increases, so will the price per tonne (Forestry Commission, 2012). In addition, the price of straw in 2012 has more than doubled since 2003.

Thus with the rise in prices of traditional bedding material (i.e. straw or sawdust), farmers are considering alternatives including re-cycled paper, woodchip, ground mollusc shells and gypsum from recycling plasterboard. The added advantage of using gypsum, apart from meeting a range of criteria for use as a bedding material (absorbent; little or no adverse effect on animal welfare; free of contaminants; cheap; easy to handle and fit into traditional systems), is a reduction in construction waste going to landfill.

1.2 Agriculture associated pollutants

Farming is a major polluter releasing ammonia, methane or nitrous oxide into the atmosphere or nitrogen, phosphorus, and heavy metals into soils and water courses (Department for Environment, Food and Rural Affairs, 2012; BATfarm, 2013).

The release of ammonia from manure piles or farm animals' urine has occurred since pre-historic times. However, due to increasing production over the last 50 years, the quantity of nitrogen in fertilisers and animal feeds has increased dramatically, and this in turn has lead to an increase of nitrogen excretion and release (Department for Environment, Food and Rural Affairs, 2002a). Over 80% of all ammonia emissions (estimated to be 320 kilotonnes in 2000) in the UK can be attributed to farming activities, the majority (74%) coming from the management of manure and slurry. Of the emissions associated with animal wastes 41% is emitted from the spreading of manure and slurry; 39% is emitted from animal buildings and a small quantity (6%) from the storage of manure (Department for Environment, Food and Rural Affairs, 2002b).

Of the world's total greenhouse gases emission from the dairy industry, methane is the important contributor accounting for greater than 50 percent of these emissions; nitrous oxide ranges from 27 to 38% of the total emissions and carbon dioxide between 5 to 10% (Food and Agriculture Organisation, 2010). Overall, the entire dairy industry (on farm, associated transportation, end product production) is estimated to contribute 4% (or 49 gigatonnes) of the total anthropogenic greenhouse gas emissions (Intergovernmental Panel on Climate Change, 2007). In the UK, the agriculture sector was considered to produce in 2010 about 8% of total greenhouse gases emissions equivalent to 50.7 metric tonne carbon dioxide equivalent (MtCO2e). Nitrous oxide contributed 56% of total agriculture emissions, largely from fertiliser use on agricultural soils, and methane 36% of emissions mainly from enteric fermentation and manure (Committee on Climate Change, 2013).

1.3 Aim of the study

Given the desire to reduce pollutants arising from the agricultural industry, this project aims to assess the viability of the use of re-cycled gypsum in the Scottish agricultural sector.

2. MATERIALS AND METHODS

2.1 Test vessels and stock slurry

Model slurry tanks were created from 45l drums, the lids of which were pre-drilled with one 15mm hole to which a plastic straight coupling joint was inserted to permit air exchange but prevent excessive rain ingress. Each barrel was also fitted with mixing paddles for use in agitation experiment. All slurry used in the experiment was collected on the same day from a local dairy farm's underground slurry tank and stored in sealed drums until required.

2.2 Gypsum application

The gypsum application rate, defined as standard, was derived from investigations conducted at a Scottish farm where 25 tonnes of recycled plasterboard were used in 3 months, over the winter period, to bed 130 dairy cattle housed in a slatted floor building. Based on the slurry production data in Burton and Turner (2003) this is equivalent to 40g of plasterboard per litre slurry produced. In order to represent the range of potential scenarios of plasterboard application, two additional application rates of 20g/l and 80g/l were also used.

2.3 Test regimes

Two different scenarios were evaluated: routine addition of slurry and gypsum to the test vessels and long term storage of the slurry/gypsum. The former was achieved by weekly addition of a set volume of slurry and a weighed amount of plasterboard to the drums equivalent to 20, 40 or 80g l^{-1}. Five drums were used for each gypsum application; in addition three control vessels which received the same amount of slurry were also prepared. In all drums the final volume of slurry was 30l.

The long term storage experiment was achieved by addition of full 30l of slurry and 1200g gypsum (40g l^{-1}) at the commencement of the trial. Tests were conducted in triplicate alongside two control vessels which only received slurry.

2.4 Headspace gas evaluation

The gas levels in the headspace above the slurry in all vessels were determined using an Eagle 2 gas meter (RKI Instruments Inc., California, USA) capable of measuring six gases: methane (0 – 50000ppm); ammonia (0 – 100ppm); hydrogen Sulphide (0 – 100ppm); carbon monoxide (0 – 500ppm) and carbon dioxide (0 – 60% volume). The external probe of the Eagle 2 meter was inserted 15cm into each barrel and after one minute the concentration of each gas was recorded. Gas levels were recorded weekly prior to any addition of fresh slurry.

2.5 Effect of mixing slurry

To evaluate the effect of pre-mixing slurry prior to field application, each barrel was stirred for 5 seconds followed by a 30 second equalisation period prior to headspace gases being monitored.

3. RESULTS

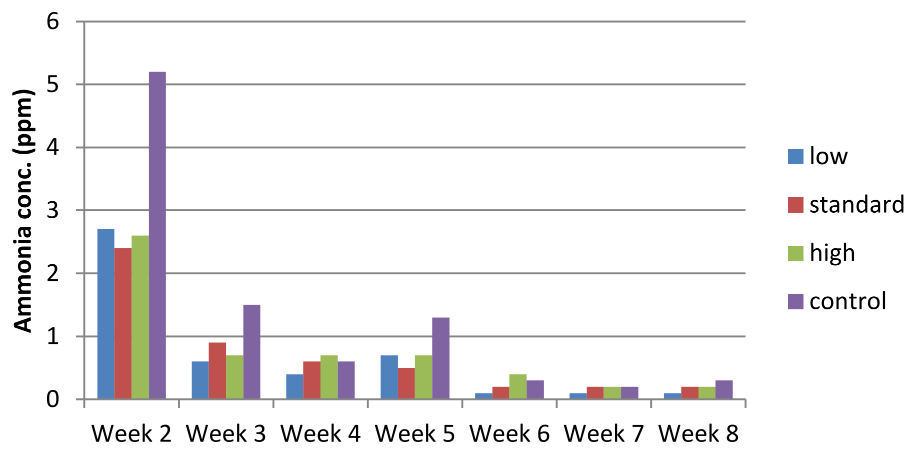
3.1 Routine monitoring of headspace gases above simulated slurry stores.

Over the monitoring period hydrogen sulphate, carbon dioxide or carbon monoxide was not detected in any of the test vessels from both the weekly addition and long term storage experiments. Ammonia and methane was detected in all vessels and in all weeks.

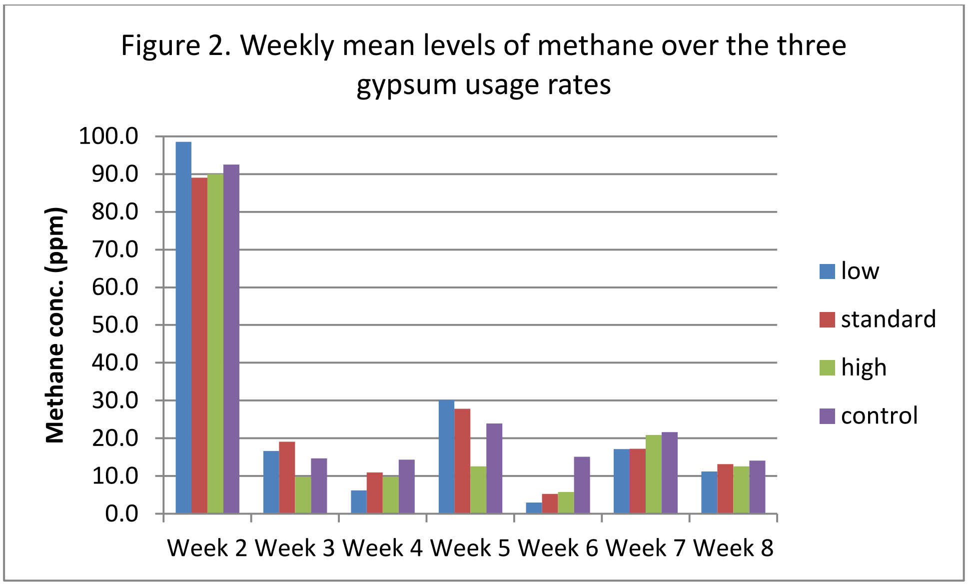
3.1.1 Weekly addition of slurry

All three gypsum application levels produced a similar effect (Figure 1), suppressing the release of ammonia by 19 to 53% compared to the control over the duration of the experiments. Overall, the use of gypsum suppressed the release of ammonia by 34%. The level of ammonia in the headspace was greatest during the early weeks peaking at 18.5ppm in the barrels with gypsum and 26.5 parts per million (ppm) in the control barrels. The concentration of ammonia dropped with time, which could be due partly to the fall in ambient temperatures which dropped from 12.5°C at the start of the trial to 2°C at the end.

Figure 1. Weekly mean levels of ammonia over the three gypsum usage rates

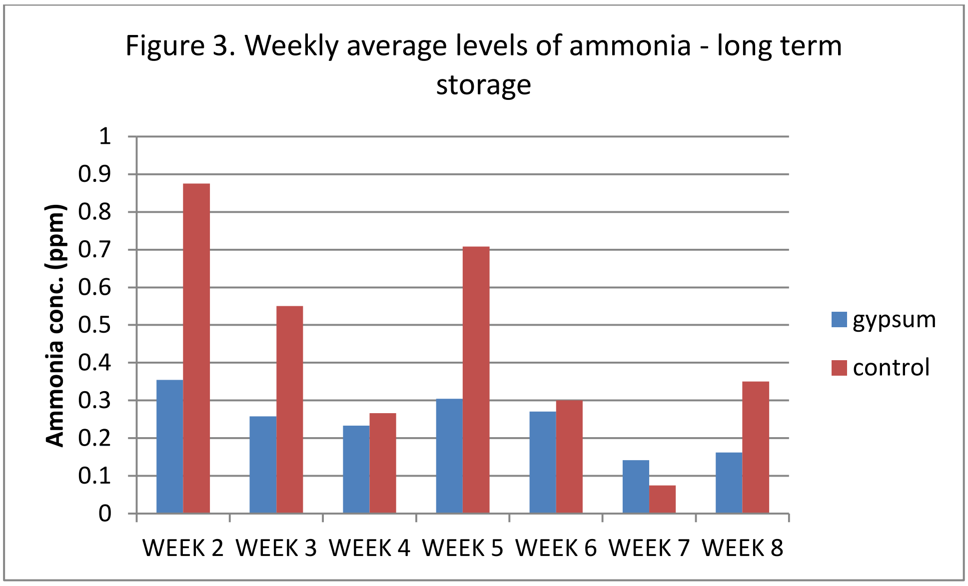


The monitoring of hydrocarbon levels (methane) were more erratic but showed a similar trend to that of ammonia (Figure 2). Peak values of 670ppm and 1050ppm were recorded in the control vessels and those with gypsum. Overall the use of gypsum suppressed the release of methane by 19% compared to control levels.



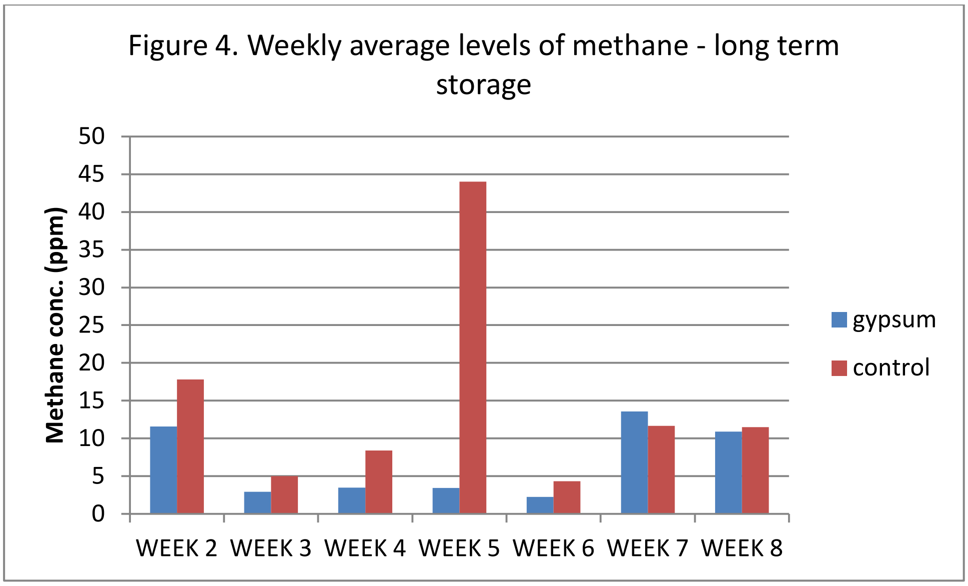
3.1.2 Long term storage of slurry

The long term storage experiment, designed to simulate storage of slurry during periods (i.e. winter) which are non conducive to spreading, revealed that ammonia in the headspace was present at a lower level than during the weekly addition experiment (Figure 3), ranging from 0.1ppm to 0.4ppm. Again, in the latter weeks, when the temperature was around 2°C, ammonia emission rates decreased. Taken over the monitoring period, ammonia levels were on average 22% lower in headspace above slurry containing gypsum than above slurry alone.



As with the weekly addition of slurry, methane levels were variable in the headspace above the test and control vessels (Figure 4). Overall, the level of methane and other hydrocarbons was 38 % lower in the test vessels; however the results are skewed by one control high reading taken at week 5.

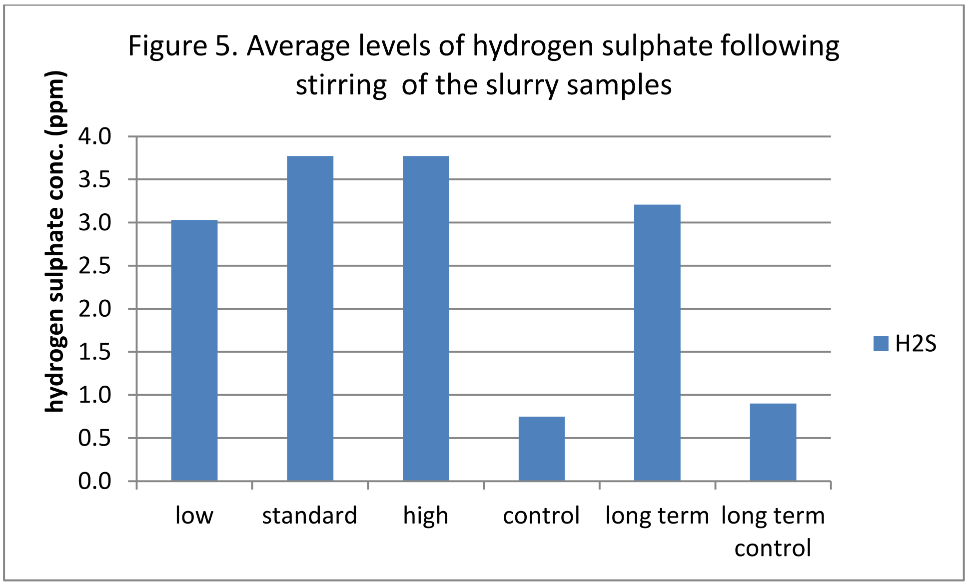
Without this week the average reduction in methane was 29% in the test vessels compared to the controls.



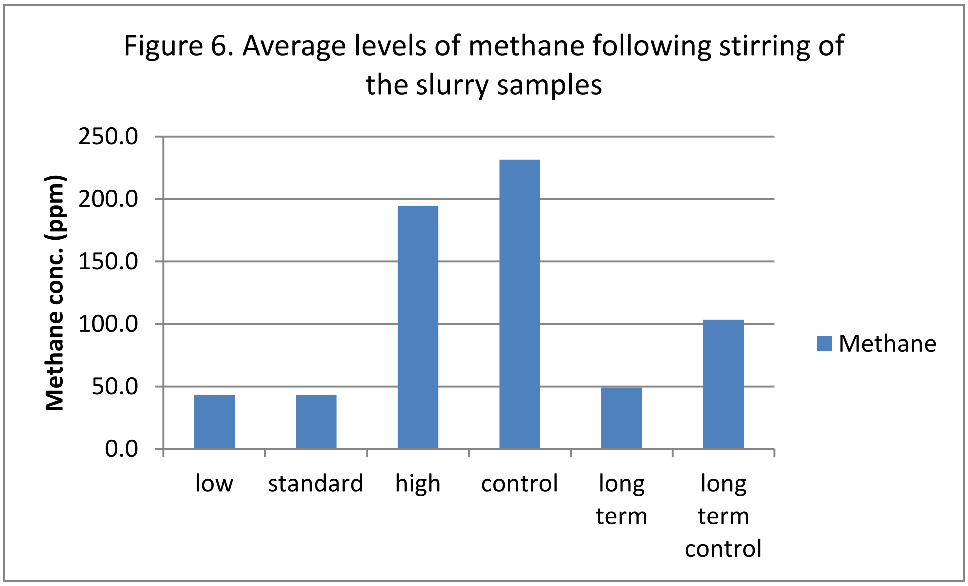
3.2 Effect of agitation on headspace gases within simulated slurry stores

Carbon monoxide was not detected in any of the test vessels and levels of carbon dioxide and ammonia were less than or equal to 0.02ppm.

Hydrogen sulphide was detected in the headspace of all vessels irrespective of the presence or absence of gypsum (Figure 5). Levels of this gas were higher above slurry containing gypsum; in the vast majority of the gypsum containing vessels (84%) the level exceeded the gas analyser maximum value (100ppm) so that an accurate indication of the actual level was not possible. Levels in the control vessels were all less than 40ppm. The effect of gypsum on potential hydrogen sulphide production cannot be accurately determined but it is at least a factor of 3.5.



Average levels of methane, after stirring, were lower in the gypsum containing vessels than in the control vessels (Figure 6). Why the levels in the low and standard gypsum application vessels were so low is unclear. In these vessels there was a five fold reduction on methane emission.



4. DISCUSSION

Agricultural activity is known to lead to a number of detrimental environmental effects such as pollutant discharges to the atmosphere typically ammonia, methane or nitrous oxide or contamination of soils and surface waters most commonly by nitrogen, phosphorus, and heavy metals (Department for Environment, Food and Rural Affairs, 2012; BATfarm, 2013).

Under the Thematic Strategy on Air Pollution (Commission to the Council and the European Parliament, 2005), the European Commission established health and environmental objectives for the year 2020 for a number of key pollutants (including ammonia). The UK was required to cut ammonia emissions by over 25 kilotonnes, compared to the 2000 figure, and to cut by over 55 kilotonnes in 2020. In the Carbon Plan (Department of Energy & Climate Change, 2011), the Government has committed to reducing emissions by 3 $MtCO_2e$ in England in 2020 (equivalent to 4.5 $MtCO_2e$ across the whole of the UK) by measures including improved soil management and cattle health, dietary changes and anaerobic digestion systems.

To achieve these targets the UK Government is encouraging farmers to be improve efficiency in their use of, for example, fossil fuels or fertilisers or to change their current practice by modifying feedstocks or adapting current best available techniques (BATs) when dealing with animal slurry to reduce ammonia emission. These BATS cover buildings, slurry/manure storage and field spreading.

4.1 Ammonia emission reduction

The aim of this study was to evaluate the potential of the use of recycled plasterboard, when used as slurry drying agent in dairy housing, to reduce ammonia emissions. Under the test conditions used, recycled gypsum reduced the level of ammonia in the headspace by between 22% and 34%. In the only other study known to the authors, Iowa State University reported that the use of gypsum reduced ammonia losses by 14% from dairy manure storage and by 8% when surface-applied to dairy manure (Iowa State University, 2004). No further information is available regarding application rates or procedure.

In other studies examining means of reducing ammonia emissions, the addition of paper to pig slurry reduced ammonia volatilization by 29-47% (Subair et al., 1999). The addition of 2.5% alum to dairy slurry reduced ammonia release by nearly 60% (Lefcourt and Meisinger, 2001). Iowa State University reported that the application of triple superphosphate, superphosphate and calcium chloride reduced ammonia losses by 33, 24 and 13%, respectively (Iowa State University (2004). Milic et al. (2005) found the addition of 2% zeolite reduced ammonia emissions by 33% and the concentration of ammonium in pig slurry by 25%.

As the ammonium:ammonia ratio in any slurry is dependent on pH, attempts have been made to reduce the pH of the slurry and thus converting more nitrogen into ammonium rather than released as ammonia gas. Stevens et al. (1989) demonstrated the use of sulphuric acid as a means of reducing ammonia emissions when applied to cattle and swine manure. A disadvantage of this approach was while it trapped ammoniacal nitrogen it increased the release of hydrogen sulphide and other odours produced from the anaerobic slurry environment.

The use of additives to slurry have to be evaluated both in terms of their efficacy at reducing ammonia and the cost to the farmer (and environment). Using recycled plasterboard, has the advantage that it is a “waste” product, which otherwise may end up in landfill, and hence currently is marketed at a lower price per tonne than alternatives such as sawdust.

4.2 Effect on hydrogen sulphide production

The production of hydrogen sulphide is frequently associated with slurry tanks and lagoons and is of increased importance when these storage units are located below animal housing.

Due to its low solubility in water hydrogen sulphide is trapped in bubbles in the manure (Pickrell, 1991). Stirring of the slurry, as part of the removal/spreading process, can release the gas leading to a rapid rise in hydro sulphate concentration with potential lethal consequences. These include cattle (Hooser et al., 2000) and unfortunately humans. The UK Health and Safety Executive reported on 35 cases of human hydrogen sulphide poisoning between 1990 and 2003, of those around 50% were associated with biological decomposition of organic matter. These include sewage treatment works; distillery biological effluent treatment plant and pig and cattle farms (Danielsson et al., 2009).

Hydrogen sulphide was not released (or only at levels below the detection limit of the equipment used) from the slurry during the static trial but was detected after stirring the slurry. This observation is consistent with other studies and the current best practice guidance from the Scottish Agricultural College (2012a), Teagasc (2012) and others.

In laboratory trials, Clark et al. (2005) found that hydrogen sulphide concentrations rose from <10 $\mu L\ L^{-1}$ to >120 $\mu L\ L^{-1}$, exceeding the range of the instrument used, following agitation. Scully et al. (2007) recorded levels of hydrogen sulphide of 275 ppm on an Irish farm following mixing of slurry, where the pre-mixing level was 7ppm.

Very high levels of hydrogen sulphide have been detected both on farms where gypsum had been used as part of the bedding system (Scottish Agricultural College, 2012b) and where there was no evidence of its usage (Health and Safety Executive for Northern Ireland, 2013). The Scottish Agricultural College (SAC) evaluated the levels of hydrogen sulphide in an open sided roofed cattle court where gypsum had been mixed with the straw bedding. Levels were monitored inside and outside the building before any agitation of the manure, as well as after agitation. SAC reported that, after disturbance, hydrogen sulphide up to 2705 ppm was detected (Scottish Agricultural College, 2012b). Tests on farms carried out by Health and Safety Executive for Northern Ireland, revealed that within minutes of the slurry pump starting levels up to 2000 ppm of hydrogen sulphide in the atmosphere were detected (Health and Safety Executive for Northern Ireland, 2013).

4.3 Reduction of hydrogen sulphide emissions

There is clearly an issue with hydrogen sulphide production and farm yard manure/slurry and advice from Scottish Agricultural College is clear “Before starting, take all animals out of the building and open all ventilation, doors etc. Never enter the building when the pump mixing the slurry or emptying the store is working.” and stringent “If entry is absolutely necessary, only appropriately supervised, competent persons, equipped with harness, lifeline and breathing apparatus, should enter slurry storage cellars and tanks." (Scottish Agricultural College, 2012a).

Systems and additives have been evaluated in an attempt to reduce or eliminate hydrogen sulphide. Predicala et al. (2008) in a pilot study used sodium nitrite and sodium molybdate to reduce the hydrogen sulphide emissions arising from pig slurry. These authors found that these chemicals decreased the concentration of the hydrogen sulphide in the headspace gas from an initial value of 500µl l^{-1} to a level in the range 2–25µl l^{-1}. Subsequently Predicala et al. (2012) in another pilot study reported that the addition of zinc oxide nanoparticles into the manure achieved more than 95% reduction in peak hydrogen sulphide levels. The cost of adding this compound to slurry was prohibitory but showed promise when used as a scrubbing filter.

Scully et al. (2007) evaluated the efficacy of a commercial "low rate aeration system" to reduce the concentration of hydrogen sulphide in a slatted livestock building. Compressed air, (25 m^3 hr^{-1}) was passed through the slurry via 36 outlets, attached to the floor of the slurry pit. Air was passed into the slurry for 36 minutes every two hours (each outlet being operated for 1 minute). After 99 days (winter housing period) concentrations of hydrogen sulphide gas were generally < 10ppm even during pumping of slurry. However no indication of installation, maintenance or running costs were provided.

4.4 Conclusions

This study, while only being a pilot, does indicate the potential for recycled plasterboard to be used in the Governments drive to reduce emissions for farms. Further on-farm trials are required to confirm the findings of this study and also to evaluate the effect of this product on emissions arising from animal housing.

The use of gypsum will increase the hydrogen sulphide concentration in slurry, thus consideration should be given to means control this gas or restricting the use of gypsum to situation where the entrapment of hydrogen sulphide is a lesser problem (i.e. above-ground or stand-alone slurry tanks).

5. ACKNOWLEDGEMENT

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