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On-farm trials of practical options for hydrogen sulphide removal from piggery biogas

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ABSTRACT

Manure-derived biogas is increasingly used at Australian piggeries to produce heat and generate electricity. However, high concentrations of hydrogen sulphide (H_2S) in piggery biogas is discouraging further use, because of a lack of practical, cost-effective H_2S removal options. To address this issue, on-farm trials were conducted at two piggeries. One trial tested H_2S oxidation; adding small amounts of air to biogas, upstream of a low-cost enhanced surface treatment vessel which was fabricated on-farm with intrinsic safety measures. Covered anaerobic pond (CAP) effluent provided a convenient, low-cost nutrient source for the biofilm of naturally-occurring microorganisms in the packed column. This treatment was effective, removing over 90% of the H_2S in a single pass and reducing H_2S concentrations from 4000 ppm to <400 ppm. Another trial tested chemisorption performance of natural, iron-rich red soil, mixed with a ground sugar cane mulch bulking agent, in comparison with cg5 commercial media (iron-oxide pellets). The red soil removed H_2S, but had a substantially lower capacity (~2 g S/kg red soil) than the cg5 (~200 g S/kg media). Accordingly, red soil is unlikely to be feasible as a primary treatment medium, but may be useful for final polishing after an oxidation step has removed most of the H_2S.

1. Introduction

Currently, about 13.5% of total Australian pork production is sourced from farms which capture biogas from piggery effluent. Biogas is used to produce heat and/or generate electricity on-farm and offers considerable potential to reduce greenhouse gas (GHG) emissions from pork production (Wiedemann et al., 2016). However, high concentrations of hydrogen sulphide (H_2S) in raw piggery biogas (500–3000 ppm) (Safley and Westerman, 1988; Heubeck and Craggs, 2010; Skerman, 2013) are discouraging further on-farm biogas use in Australia, specifically due to a lack of practical and cost-effective H_2S removal options. Many commercial H_2S removal methods exist (Ryckebosch et al., 2011), but have limited applicability on typical Australian farms because of high cost, complexity and associated safety issues. Other options for H_2S removal are still being explored in the literature, such as recent research (Tilahun et al., 2017 and Tilahun et al., 2018) with a hybrid membrane gas absorption and bio-oxidation process at laboratory scale.

Biological oxidation could be a feasible H_2S removal option. With this method, a small amount of air is added to the biogas (2–6% of total volume, Wellinger and Linberg, 2005), allowing microorganisms to oxidise H_2S into elemental sulphur and/or sulphuric acid. This can occur inside a digester or in an external treatment vessel (Ryckebosch et al., 2011), as long as oxygen, nutrients, moisture and an active inoculum are provided, and conditions are conducive to microbial activity. At the time of writing, most Australian piggery installations were using covered anaerobic ponds (CAPs) rather than heated, mixed tank digesters for biogas production, because of Australia's warm climate, land availability and the low capital cost of these systems. A preliminary trial at an Australian piggery involved the careful addition of air under the cover of a CAP, which showed a decrease in H_2S concentration from 1300 ppm to less than detectable levels (<100 ppm). Methane concentration decreased

Abbreviations: ANOVA, analysis of variance; BSP, British standard pipe thread; CAP, covered anaerobic pond; CH_4, methane; CO_2, carbon dioxide; DN, nominal diameter; FRP, fibre-reinforced plastic; GHG, greenhouse gas; H_2S, hydrogen sulphide; kWe, kilowatt (electric); LSD, least significant difference; N_2, nitrogen; NB, nominal bore; O_2, oxygen; OD, outside diameter; pCAP, partially covered anaerobic pond; ppm, parts per million; S, sulphur; SCM, sugar cane mulch; SWJ, solvent weld joint; UPVC, plasticized polyvinyl chloride.

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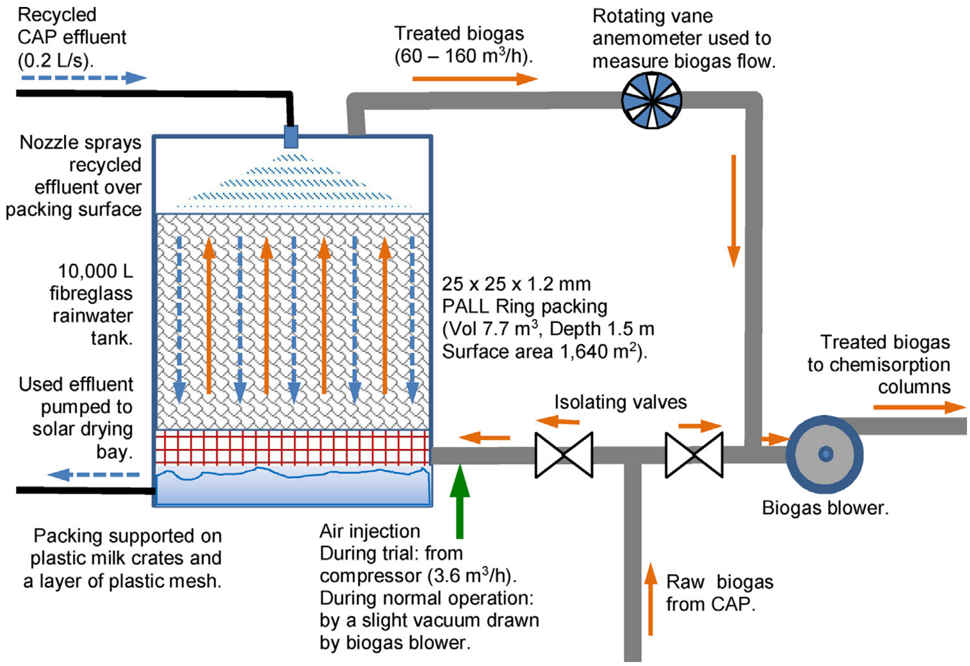

Fig. 1. Schematic drawing of the H_2S removal system trialled at piggery A, employing oxidation in an external vessel.

only marginally from 58 vol% to 52 vol% (Tait, 2014). These results were promising, but the distribution of air under a large cover is generally unreliable when not closely monitored. In addition, elemental sulphur is likely to form and may accumulate in a CAP and be converted back into H_2S, thereby exacerbating the H_2S load over time. This result was observed in the preliminary trial above. When the air supply was stopped, the H_2S concentration rapidly increased to a much higher level of around 3000 ppm before gradually returning to a level around 1300 ppm over a 1-month period (Tait, 2014). For on-farm CAP installations, oxidation in an external treatment system may be preferable and easier to control. It is of interest to test this approach on-farm, using effluent from a piggery CAP as a cost-effective moisture, nutrient and inoculum source. This would minimise the complexity and operating costs of H_2S removal.

Chemisorption with commercial iron oxide pellets containing iron (III) (Eq. (1), Ryckebosch et al., 2011) could be a feasible treatment method (Wellinger and Linberg, 2005; Skerman, 2017) and some Australian piggeries currently use this method.

$$Fe_2O_3 + 3H_2S \rightarrow Fe_2S_3 + 3H_2O \quad (1)$$

However, there are on-going safety concerns with change-outs of spent commercial media, when large quantities of heat are released as the spent media regenerates following exposure to ambient air (Eq. (2), Zicari, 2003).

$$2Fe_2S_3 + O_2 \rightarrow 2Fe_2O_3 + 3S_2 \Delta H = -198\,\text{kJ/g-mol}H_2S \quad (2)$$

If media are not pre-wetted before a change-out, hazardous sulphur combustion products may be emitted. If pre-wetted, the pellet structure of the media tends to collapse, making it difficult to remove from the chemisorption vessel and affecting the potential to regenerate and reuse the media. To identify cost-effective alternatives to commercial media, a previous laboratory study (Skerman et al., 2017) compared H_2S removal of commercial iron-oxide pellets with that of a number of alternative media. An iron-rich red soil was identified as a promising candidate (Skerman et al., 2017); however, the performance of the red soil required further testing at on-farm scale. Specifically, scale-up effects may influence on-farm performance, such as the formation of preferential flow paths with sub-optimal gas-solid contact. In addition, on-farm biogas composition and flowrates tend to vary considerably over time, which may affect chemisorption performance.

To develop and test promising H_2S removal options, the present study carried out on-farm trials at two separate Australian piggeries. At one piggery, a simple oxidation concept was tested with air added upstream of an enhanced surface treatment vessel, which was supplied with effluent from an onsite CAP to provide the liquid and nutrient source for sustaining the oxidation reactions. At another piggery, field-scale chemisorption was tested for red soil, mixed with ground sugar cane mulch as a bulking agent, to reduce frictional pressure loss through the media.

2. Materials and methods

2.1. H_2S removal at Piggery A by oxidation in an external vessel

At piggery A, a new H_2S removal system was designed by the farm owners, with some specialist support, and was constructed and installed using off-the-shelf equipment and local labour. This piggery was a grower-finisher unit (Gopalan et al., 2013) located near Young, New South Wales, Australia, housing 15,000 weaner to finisher pigs (8–100 kg live weight). An onsite CAP treated the manure flushed from the pig housing on a regular basis, and biogas was captured and used for on-farm heat and electricity generation. Prior to the installation of the new H_2S removal system, two 500 L chemisorption vessels (duty/standby) loaded with commercial iron oxide pellets were being used to treat the biogas captured in the CAP. The new H_2S removal system treated biogas supplying two 80 kWe reciprocating generators. Some surplus biogas was exported to a second piggery, resulting in a maximum raw biogas flowrate of 160 m^3/h. The farm owners' primary objectives for installing the new H_2S removal system were to reduce operational costs and to address on-going safety concerns associated with change-outs of a commercial chemisorption medium.

2.1.1. Field set-up – Piggery A

The new H_2S removal system (Fig. 1) consisted of a 10,000 L fibreglass (FRP) tank (Tankworld, 2.56 m OD at mid-height, height 2.2 m), partially filled with 7.7 m^3 of a general purpose plastic pack-