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# Pilot-scale testing of a leachbed for anaerobic digestion of livestock residues on-farm

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## ABSTRACT

A leachbed is a relatively simple anaerobic digester suitable for high-solids residues and on-farm applications. However, performance characteristics and optimal configuration of leachbeds are not well-understood. In this study, two 200 L pilot-scale leachbeds fed with spent straw bedding from pigs/swine (methane potential,  $B_0 = 195\text{--}218 \text{ L CH}_4 \text{ kg}^{-1} \text{ VS}_{\text{fed}}$ ) were used to assess the effects of leachate recirculation mode (trickling vs. flood-and-drain) on the digestion performance. Results showed comparable substrate solubilisation extents (30–45% of total chemical oxygen demand fed) and methane conversion (50% of the  $B_0$ ) for the trickling and flood-and-drain modes, indicating that digestion performance was insensitive to the mode of leachate flow. However, the flood-and-drain leachbed mobilised more particulates into the leachate than the trickling leachbed, an undesirable outcome, because these particulates were mostly non-biodegradable. Inoculation with solid residues from a previous leachbed (inoculum-to-substrate ratio of 0.22 on a VS basis) hastened the leachbed start-up, but methane recovery remained at 50% of the  $B_0$  regardless of the leachate recirculation mode. Post-digestion testing indicated that the leachbeds may have been limited by microbial activity/inhibition. The high residual methane potential of leachate from the trickling (residual  $B_0 = 732 \pm 7 \text{ L CH}_4 \text{ kg}^{-1} \text{ VS}_{\text{fed}}$ ) and flood-and-drain leachbeds ( $582 \pm 8 \text{ L CH}_4 \text{ kg}^{-1} \text{ VS}_{\text{fed}}$ ) indicated an opportunity for further processing of leachate via a separate methanogenic step. Overall, a trickling leachbed appeared to be more favourable than the flood-and-drain leachbed for treating spent bedding at farm-scale due to easier operation.

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## 1. Introduction

The use of bedding is common in intensive livestock production. Animal welfare can be maintained with high stocking densities because the bedding absorbs moisture, and reduces odour and ammonia (Aland and Banhazi, 2013). Common bedding materials include straw, barley, woodchips and rice hulls (Kruger et al., 2006). The animals are typically grown in a batch “all in, all out” mode, with batch times varying depending on the type of livestock and farm operations (Aland and Banhazi, 2013). A key by-product from bedded animal housing is a soiled lignocellulosic residue, known as spent bedding, which mainly consists of residual bedding, faeces, urine, spilt water and animal feed (Tait et al., 2009). Spent bedding is typically stockpiled for passive composting prior to re-use as a soil conditioner and fertiliser on-farm. Key concerns from stockpiling are greenhouse gas (GHG) emissions, odour, loss

of nutrients, and potential ground and surface water contamination (Sommer and Möller, 2000).

Anaerobic digestion (AD) is a technology option for valorising solid waste (Mata-Alvarez et al., 2000), with significant advantages over conventional stockpiling, such as renewable energy recovery, reduced odour (when operated correctly) and improved nutrient recovery potential. AD is a multistep biological process and for a solid substrate like spent bedding would probably be limited by the rates of both hydrolysis and methanogenesis (Batstone and Jensen, 2011).

Single-stage solid-phase anaerobic leachbeds, also known as percolation or batch solid-phase digesters, is a dry digestion process and thus can operate at relatively high solids content (>20%) (Batstone and Jensen, 2011), making it particularly interesting for solid livestock residues. Further, a leachbed process can be relatively simple to construct and operate and thus cost-effective when compared to technology alternatives such as plug flow or mixed vessel digesters (Deublein and Steinhauser, 2011). For these reasons, leachbeds may be particularly suitable for decentralised agricultural applications. Leachbeds have been mostly applied to the organic fraction of municipal solid waste (OFMSW) and energy

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crops, and to a lesser extent of agricultural waste, such as spent bedding (Vandevivere et al., 2003; Deublein and Steinhauser, 2011). Moisture content is a critical factor affecting solid-phase digestion, and which with a leachbed is maintained via exposure of the solid substrate to a leachate (Mussoline, 2013). Good contact between leachate and the solid being digested is thus essential, in order to provide dispersion of inoculum, nutrients, soluble digestion products and pH buffering agents (Jha et al., 2011), and to dilute inhibitors (Chugh et al., 1998).

Different leachate recirculation modes have been trialled previously to provide the necessary solid-liquid contact (Chugh et al., 1998; Kusch et al., 2008; Nizami et al., 2010). In some cases, leachate is sprayed over the solid bed and recovered from the base of leachbed for recirculation (termed trickling) (Deublein and Steinhauser, 2011). In other cases the solid bed is fully flooded with leachate (Nizami et al., 2010), which is left to contact for a period and then drained (termed flood-and-drain) (Clarke and Xie, 2013). Studies to date have suggested that the leachate contact mode can impact on digestion performance (Kusch et al., 2008; Nizami et al., 2010). For instance, Nizami et al. (2010) hypothesized that a flooded system would perform better than a trickling system, because substrate is fully submersed with more intimate contact with leachate. However, there is still a degree of ambiguity as to the preferred leachbed flow arrangement (Kusch et al., 2008; Nizami et al., 2010). Also, to our knowledge, there have not been previous studies of different leachate flow configurations tested in parallel (flooded versus trickling) nor at pilot-scale, which are important to provide insight for future applications of the leachbed technology.

Previous laboratory scale studies (Kusch et al., 2008; Tait et al., 2009) on spent bedding digestion have indicated variable background microbial activity. Inoculation may provide a balanced microbial community and pH buffering necessary for accelerated start-up of a leachbed (Shi et al., 2014; Demirel and Scherer, 2008). Inoculation of leachbeds typically uses a fraction of digested material or solid residues retained from a previous leachbed batch (Xu et al., 2012). Otherwise, an alternate inoculation technique known as 'sequencing' or 'indirect recirculation' has been used, which involves cross-circulation of water leachate between a fresh and stabilised waste (Chugh et al., 1998).

The present study evaluates leachbed digestion of spent bedding from pigs/swine at pilot-scale. Two 200 L leachbeds are operated in parallel to compare the effects of hydraulic configuration (trickling vs. flood-and-drain) on digestion performance. Also, in two separate tests, a leachbed is operated with and without external inoculation to assess the sufficiency of background microbial activity for leachbed start-up.

## 2. Materials and methods

### 2.1. Raw materials

Spent bedding was collected and prepared for analysis according to Test Methods for the Examination of Composting and Compost (U.S. Composting Council, 2002). Samples were collected from stockpiles at two piggeries (site A and B) in Queensland (Australia) and were 0–2 days old at the time of sampling. The two different sites provided some variation in the properties of spent bedding, which was a necessary factor to consider during the testing because spent bedding naturally varies across sites and with local management practices (Tait et al., 2009). At both sites, the spent bedding was from sheds housing smaller pigs (weaners). The pigs were all reared according to a batch "all in, all out" mode and the batch time of site A and B was different at 6 and 4 weeks, respectively. This meant that spent litter from site A was expectedly more

soiled. Moreover, bedding at site A consisted only of wheat straw, whilst bedding at site B contained 40 wt% wheat straw, 40 wt% barley straw and 20 wt% sorghum straw (weight basis of fresh bedding added).

### 2.2. Pilot-scale leachbed trials

Two leachbeds were operated in parallel, which were 200 L stainless steel (SS) vessels (500 mm internal diameter, 1060 mm height) fitted with perforated SS304 base plates to support and retain the spent bedding being digested. The leachate from each leachbed was collected in a separate gastight 120 L polyethylene drum (leachate storage tank), before being pumped back into the leachbed (CP 11, Monopump) at  $2 \text{ L min}^{-1}$ . When leachate was pumped back into the leachbed, it was first passed through a stainless steel shell-and-tube type heat exchanger (total heat transfer area of  $0.6 \text{ m}^2$ ) to heat the leachate (and thus the leachbed) to a desired temperature of  $37 \pm 1^\circ \text{C}$ . Pressure transducers were able to detect any blockages of the pipes through which leachate were pumped. The pH of the leachate was measured with a pH probe (Hannah Instrument) mounted through the wall of the leachate storage tank. The temperature of the leachbed was measured with a resistance temperature detector (RTD) (model SEM203P, W&B Instruments) mounted through the wall of the leachbed vessel. Pressure, pH and temperature (4–20 mA transmitter) were logged via a PLC system (DirectLogic hardware, Think & Do PC-based control software). Biogas produced by each leachbed/leachate storage tank pair was combined in a single outlet line and was measured with a displacement manometer (Chugh et al., 1999).

The two leachbeds were operated with distinct modes of leachate flow i.e. one leachbed as trickling and a parallel leachbed as flood-and-drain (see Fig. S1 of Supplementary material). In the trickling system, leachate was sprayed over the solid bed via a spray nozzle (3/8YS60130, SprayFlo) for 5 min every 20 min. With this trickling leachbed, a filter (150 mm internal diameter, 400 mm height, 3 mm mesh size) was placed in the pipeline that carried collected leachate into the leachate storage tank, in order to capture coarse or fibrous material that could have clogged the spray nozzle. However, the amount of material typically retained in this filter was usually minimal, representing a negligible portion of total chemical oxygen demand fed ( $\text{tCOD}_{\text{fed}}$ ). With the flood-and-drain leachbed, the spent bedding content was completely flooded from the base for 20 min, followed by a drain and rest for 20 min, before the fill/drain cycle was repeated using the same leachate. Three mesh conduits (5 mm mesh size, SS316) were embedded evenly spaced and vertically transverse in the spent bedding of the flood-and-drain leachbed only, to aide free-flow of leachate and improve solid-liquid contact (i.e. mass transfer) (see Fig. S1 of Supplementary material). To minimise the oxidation of organic matter added into the leachbed, the system was flushed with 100%  $\text{N}_2$  gas prior to start-up.

Two separate trials (termed Test 1 and 2) were carried out, each with the two leachbeds operating in parallel. Each trial ran for

**Table 1**  
Initial start-up conditions of leachbeds in Test 1 and 2.

	Test 1	Test 2
Spent litter origin	Site A	Site B
Substrate load (kg, wet basis)	15	10
Solid inoculum (kg, wet basis)	n/a	5
ISR (VS basis)	n/a	0.22
Liquid fraction		
Water (kg)	97.5	40
Leachate (kg)	n/a	40
Initial system TS (wt% wet basis)	$6.2 \pm 0.2$	$5.7 \pm 0.2$

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