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Impact of dewatering technologies on specific methanogenic activity

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ABSTRACT

Dewatering methods for recuperative thickening and final dewatering can potentially impact methanogenic activity and microbial community. This influences both the feasibility of recuperative thickening to increase solids residence time within a digester, and the utilisation of dewatered digestate as inoculum for new digesters. Thickening technology can reduce methanogenic activity through either air contact (rotary drum, DAF, or belt filter press), or by lysing cells through shear (centrifuge). To assess this, two plants with recuperative thickening (rotary drum) in their anaerobic digester, and five without recuperative thickening, had specific methanogenic activity tested in all related streams, including dewatering feed, thickened return, final cake, and centrate. All plants had high speed centrifuges for final dewatering. The digester microbial community was also assessed through 16s pyrotag sequencing and subsequent principal component analysis (PCA). The specific methanogenic activity of all samples was in the expected range of 0.2–0.4 gCOD $gVS^{-1}d^{-1}$. Plants with recuperative thickening did not have lower digester activity. Centrifuge based dewatering had a significant and variable impact on methanogenic activity in all samples, ranging between 20% and 90% decrease but averaging 54%. Rotary drum based recuperative thickening had a far smaller impact on activity, with a 0% per-pass drop in activity in one plant, and a 20% drop in another. However, the presence of recuperative thickening was a major predictor of overall microbial community (PC1, $p = 0.0024$). Microbial community PC3 (mainly driven by a shift in methanogens) was a strong predictor for sensitivity in activity to shear ($p = 0.0005$, $p = 0.00001$ without outlier). The one outlier was related to a plant producing the wettest cake (17% solids). This indicates that high solids is a potential driver of sensitivity to shear, but that a resilient microbial community can also bestow resilience. Sensitivity of methanogens to centrifuging does not rule out centrifuges for recuperative thickening (particularly where hydrolysis is rate-limiting), but may impose a maximum return rate to avoid digester failure.

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1. Introduction

Recuperative thickening is a process for intensifying anaerobic digesters, by removing water from digestate, and returning the high-solids concentrate back to the digester. It thereby increases effective solids retention time over hydraulic retention time (Reynolds et al., 2001; Vanyushina et al., 2012). It is particularly suited to primary sludge, which has a relatively high degradability extent, but which is also relatively slow to degrade, and generally poorly suited material with a limited degradability extent, since this will result in the recycling of large amounts of inert material (see model provided supplementary information SI).

Recuperative thickening is a relatively low cost technique for intensification, with well understood fundamentals, but there is very references found in the formal literature. A key practical concern is the possibility of damaging anaerobic microbes, particularly methanogenic archaea during the thickening stage. The impact of recuperative thickening on methanogenic activity is of critical importance, since the digester contents may be passed through the thickening equipment multiple times before it leaves the digester for final dewatering. The other major process of water removal from sludge is final dewatering, and indeed, centrifuges can be used for both recuperative thickening and final dewatering. The impact of final dewatering on activity is also important since firstly, dewatered sludge may be used as inoculum in other digesters, and secondly, the activity of dewatered material potentially determines methane production during storage.

Both recuperative thickening and final dewatering can be regarded as comparable processes. In the case of recuperative thickening, digester sludge is thickened to 6%–12% through a range of techniques, including centrifuges and belt filter presses (Tchobanoglous et al., 2003), dissolved air flotation (Vanyushina et al., 2012), gravity belt thickeners (Reynolds et al., 2001), and rotary drum thickeners (Tchobanoglous et al., 2003). These can be generally classed by the DS achieved and the potential impact on the biology as shown in Table 1. Final dewatering depends on high-g and standard centrifuges, or belt filter presses to produce a final cake at >12% DS (Albertson et al., 1987) whereas recuperative thickening technologies target lower DS.

The major factors that may influence activity are liquid shear and oxygen exposure (Table 1). Flocculant is not inhibitory at normal doses, and indeed, may partially degrade (Chang et al., 2001). Liquid shear occurring at impeller tip velocities >2 m s^{-1} (shear rate – G~2000 s^{-1} in a 1 mm tip field) are of concern since this lyse susceptible organisms, and may disrupt microbial syntrophic associations (Deveci, 2002; Ghyoot and Verstraete, 1997), while oxygen is toxic to methanogenic archaea in particular (Madigan et al., 2009). High-g equipment such as centrifuges (G 5000 s^{-1} (Muller, 2006))are more likely to expose organisms to shear, while dissolved air filtration, and rotary drum thickeners in particular are more likely to expose organisms to oxygen (Table 1).

Table 1 – Dewatering and thickening equipment summary.

Equipment	Performance (% DS)	Biochemical impact
High-g centrifuge	18%–30%	High shear
Centrifuge	15%–25%	Shear
Belt filter press	12%–25%	Oxygen, mild shear
Rotary drum	8%–15%	Oxygen
Baleen filter	5%–8%	Oxygen, mild shear
Dissolved air flotation	5%–8%	High oxygen
Gravity belt thickening	4%–6%	Oxygen

From Albertson et al. (1987), Tchobanoglous et al. (2003).

The issue of oxygen exposure during thickening for recuperative purposes has been previously considered. Conklin et al. (2007) (Conklin et al., 2007) assessed the impact of oxygen exposure (via sparging) as a proxy for dissolved air flotation and actual samples from a gravity belt thickener (GBT) to assess the potential use of either for recuperative thickening. They found (via activity) that mild exposure (i.e., GBT) had no impact on activity while high exposure (i.e., sparging) only had an impact, but would only be of effect at high relative recirculation rates, or where the reactor was overloaded.

The impact of centrifuge dewatering on activity has not been previously considered, either for recuperative thickening, or for final dewatering, and particularly, the impact of shear on methanogens has not been investigated. However, Deveci (2002) found that shearing had a strong impact on viability of aerobic acidophilic organisms particularly at solids concentrations above 10%. The finding was that shear alone was less likely to result in loss of activity, but that at high solids, poor momentum dissipation, and hence a high velocity gradient (i.e., shear) would result in loss of activity. Application of membrane based methods to selectively remove permeate have consistently found reduced activities at higher recirculation rates (Ghyoot and Verstraete, 1997), and high shear in a membrane configuration is correlated with a loss of acetoclastic methanogens (Padmasiri et al., 2007). As seen in Table 1, particularly mechanical dewatering equipment operates in an environment of high-shear and high solids, and the impact of dewatering equipment on anaerobes and particularly methanogens is unknown.

While there is relevant incidental literature, there is very little available on the impact of dewatering on anaerobic systems, and particularly on activity, more so for the purpose of recuperative thickening. This is surprising given the relatively feasibility and simple application of recuperative thickening to intensify anaerobic processes. This paper addresses the key gap of impact of shear (centrifuge) based dewatering and air based (rotary drum) thickening on methanogenic activity, and also assesses the impact of long-term operation using rotary drum thickening on microbial community.

2. Methods

2.1. *Digesters and sampling*

27 samples were taken from 7 sites in the Sydney greater metropolitan area (plant names given in Table 2). These included two sites with recuperative thickening (A, B – six samples each), and five sites without recuperative thickening