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Biogas stripping of ammonia from fresh digestate from a food waste digester

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HIGHLIGHTS

- Biogas stripping reduced ammonia concentrations of fresh SS-DFW digestate.
- Ammonia removal from fresh digestate was more difficult than from stored digestate.
- Hydrolysis was improved by thermal-alkaline stripping.
- *In situ* ammonia removal is not feasible at mesophilic or thermophilic conditions.
- Ammonia stripping was most effective at 70 °C and pH 10.

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ABSTRACT

The efficiency of ammonia removal from fresh source-segregated domestic food waste digestate using biogas as a stripping agent was studied in batch experiments at 35, 55 and 70 °C, at gas flow rates of 0.125 and 0.250 $L_{biogas}\ min^{-1}\ L^{-1}_{digestate}$ with and without pH adjustment. Higher temperatures and alkaline conditions were required for effective ammonia removal, and at 35 °C with or without pH adjustment or 55 °C with unadjusted pH there was little or no removal. Results were compared to those from earlier studies with digestate that had been stored prior to stripping and showed that ammonia removal from fresh digestate was more difficult, with time constants 1.6–5.7 times higher than those previously reported. This has implications for the design of large-scale systems where continuous stripping of fresh digestate is likely to be the normal operating mode. A mass balance approach showed that thermal-alkaline stripping improved hydrolysis.

1. Introduction

Source segregated domestic food waste (SS-DFW) represents a large biomass waste stream: stabilisation of this by anaerobic digestion (AD) can help towards meeting environmental protection targets such as the EU Directive on the landfilling of waste (1999/31/EC). Further added value benefits are the recovery of a fuel gas and the provision of a mechanism by which nutrients can be recycled back to land through digestate application. Although anaerobic digestion can offer numerous benefits (EC, 2010), the digestion of SS-DFW can also present operational difficulties, primarily due to its high protein content. Hydrolysis of this material releases free and ionised ammonia: the latter is essential for the growth of anaerobic microorganisms, but both forms can be inhibitory to the anaerobic consortium, including methanogenic *Archaea*, and especially to the acetoclastic methanogens (Angelidaki and Ahring, 1993; Kayhanian, 1999; Liu and Sung, 2002; Schnürer and Nordberg, 2008). Partial inhibition of methanogenesis can cause operational instability due to volatile fatty acid (VFA) accumulation, leading to a decrease in biogas production, and in the worst cases to failure of the digestion process (Angelidaki and Ahring, 1993; Poggi-Varaldo et al., 1997; Hansen et al., 1998).

Banks et al. (2012) showed that, given appropriate trace element supplementation to stimulate acetate oxidation and hydrogenotrophic methanogenesis, mesophilic AD of SS-DFW could be achieved without reducing the total ammonia nitrogen (TAN) concentration by water addition. More recent work (VALORGAS, 2013) has shown that with this trace element supplementation, operation at TAN concentrations above 6 g N L^{-1} and an organic loading rate (OLR) up to 8 g VS L^{-1} day^{-1} is possible with no loss in digestion performance. An increase in temperature to the thermophilic range, however, leads to an increase in the ratio of free ammonia nitrogen (FAN) to TAN from 11% to 28%, which in turns reduces

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the threshold of ammonia toxicity, and thus thermophilic digestion of SS-DFW is unstable. This was clearly demonstrated in a comparative study by Yirong et al. (2013a) which showed the onset of failure in thermophilic SS-DFW digesters when TAN concentrations reached 3.0 g N L^{-1}. A parallel study with acclimatisation to thermophilic conditions using a low nitrogen (1.45% of dry weight) synthetic food waste showed long-term stable operation was possible in thermophilic conditions, while subsequent increases in the nitrogen concentration by addition of urea to this feedstock confirmed that the critical TAN concentration was between 2.5 and 3.0 g N L^{-1} (Yirong et al., 2013b; VALORGAS, 2013), equivalent to FAN concentrations of 590–710 mg N L^{-1} at the operational pH. This threshold value is similar to that reported in other studies where suppression of methanogenic activity as a result of ammonia toxicity has been demonstrated in thermophilic systems (Angelidaki and Ahring, 1993; Borja et al., 1996; Hansen et al., 1998; Angelidaki et al., 2006; Nielsen and Ahring, 2007).

To maximise the specific methane yield in thermophilic digestion of SS-DFW while avoiding VFA accumulation and process instability, one approach is to reduce the TAN concentration in the digester by gas stripping. Ammonia stripping has been trialled using a range of approaches, including with and without solid/liquid separation and using air, nitrogen, steam or biogas as the stripping agent (Bonmati and Flotats, 2003; Ledda et al., 2013; Jiang et al., 2013; Nie et al., 2015; Zeng et al., 2006; Walker et al., 2011). Stripping with biogas has several advantages: the cost is low since biogas is produced on site in the anaerobic digestion process, and the risk of stripping carbonate from the digestate is reduced. Ammonia stripping on the feedstock prior to digestion can only be successfully applied to materials such as manures where a high percentage of the total Kjeldahl nitrogen (TKN) is present as TAN. In the case of SS-DFW this is not feasible, as only about 7% of TKN in kerbside collected food waste is available as TAN, and further pre-hydrolysis leads to rapid acidification and lowering of pH (Defra, 2010). An alternative is to allow hydrolysis to proceed in the digester itself, as is normal, and then remove ammonia in a side-stream stripping configuration. This approach has some merit, as previous studies have reported an increase in stripping efficiency at higher alkalinities and ammonia concentrations (Campos et al., 2013); digestion also lowers the organic matter content, which reduces cation binding and increases the proportion of ammonia that is strippable. Laureni et al. (2013) found that digestate storage decreased the total solids, chemical oxygen demand, VFA concentration and alkalinity and improved the ammonia stripping efficiency. Other factors may also affect the binding capacity of digestate for ammonia; but the above findings clearly indicate that the ammonia stripping process is strongly dependent on digestate characteristics. These results therefore throw some doubt on the kinetic values and time constants reported in the studies by De la Rubia et al. (2010) and Walker et al. (2011), which used digestate that had been stored over long periods. The methodology employed in these studies was effective, however, and showed the value of using biogas as the stripping medium at flow rates between 0.125 to 0.750 $L_{biogas}\ min^{-1}\ L^{-1}_{digestate}$, and at different temperatures (35, 55 and 70 °C), with and without pH adjustment using NaOH. A similar approach was thus adopted in the current study, but with the important difference that fresh digestate samples were taken directly from an operational food waste digester for each experimental run. The main objective of the current work was thus to gather data on the ammonia stripping performance parameters of fresh SS-DFW digestate under a number of different stripping conditions, to provide data for the design of side-stream systems coupled to anaerobic digesters as a means of reducing TAN concentrations to non-inhibitory values for thermophilic digestion.

2. Methods

2.1. Food waste digestion

Two 75-L working volume continuously-stirred tank reactors (CSTR) as previously described by Zhang et al. (2012) were operated as food waste digesters at a temperature of 36 ± 1 °C (Fig. 1a). They were inoculated with digestate from a commercial AD plant treating SS-DFW (Biocycle digester, operated by BiogenGreenfinch, Ludlow, UK). The digesters were then fed daily on SS-DFW collected commercially by Veolia Environmental Services (UK) from households in Eastleigh, Hampshire, UK. A

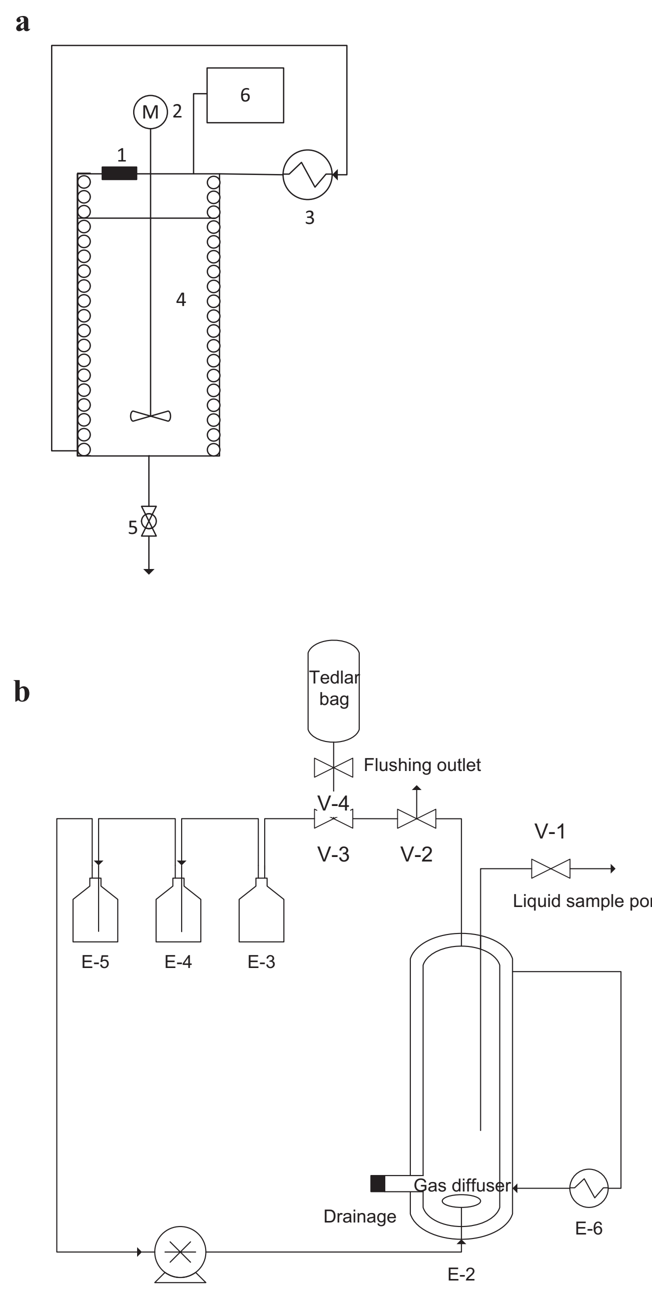

Fig. 1. Details of experimental set-up: (a) 75-L CSTR digesters. (1) Feed port, (2) stirrer motor, (3) heater, (4) heating coil, (5) digestate outlet; (6) gas meter in line with gas-impermeable bag for gas collection at atmospheric pressure (b) diagram of batch ammonia stripping system. (E-1) peristaltic pump, (E-2) stripping column with heating jacket, (E-3) condensate trap, (E-4) water trap, (E-5) acid trap, (E-6) heater.