1 THESIS ABSTRACT

Anaerobic digestion (AD) is an attractive waste treatment process in which both pollution control and energy recovery can be achieved. Source-segregated domestic food waste (FW) has high organic content on a dry weight basis and is rich in lipids and proteins, indicating the potential for a good biogas yield with high methane content. Process instability, however, was often reported in food waste digesters, which was mainly manifested by the accumulation of volatile fatty acid (VFA) and reduction of specific methane production. Trace element (TE) supplementation has been proved to be an effective way to rectify this problem and has been applied to industrial AD plants. This practice, however, was usually characterised by trial-and-error approach due to lack of clear understanding of the impact of TEs on AD under different process conditions. The aim of this study was therefore to optimise TE dosing strategies for FW digestion at different loading rates, with particular attention to the role of cobalt (Co) and selenium (Se).

The limiting concentrations of Co and Se were studied in long-term continuously stirred tank reactor (CSTR)-type digester operation at organic loading rate (OLR) from 1.8 to 5 kg volatile solids (VS) m\(^{-3}\) day\(^{-1}\). In the digester operated at OLR 1.8 kg VS m\(^{-3}\) day\(^{-1}\) without TE addition, dosing of Co at strength of 1 mg Co kg\(^{-1}\) fresh matter was effective to stimulate the complete degradation of accumulated VFA. Around 2500 mg L\(^{-1}\) VFA, however, built up after OLR increased to 2.5 kg VS m\(^{-3}\) day\(^{-1}\), which dropped slightly by addition of Se at a strength of 0.05 mg Se kg\(^{-1}\) fresh matter. After stepwise increase of Se concentration to 0.2 mg kg\(^{-1}\), VFA reduced to less than 1000 mg L\(^{-1}\).

In another 2 digesters, at OLR 3 and 4 kg VS m\(^{-3}\) day\(^{-1}\) respectively, TE washing-out was introduced for the determination of limiting Co concentration. All TE supplementation were ceased in these 2 digesters for around 300 days with the exception of continuous addition of 0.2 mg kg\(^{-1}\) of Se, and VFA accumulation up to 30000 mg L\(^{-1}\) occurred in one digester immediately after OLR increased from 4 to 5 kg VS m\(^{-3}\) day\(^{-1}\) and later up to 22500 mg L\(^{-1}\) in the other digester with OLR increased from 3 to 4 kg VS m\(^{-3}\) day\(^{-1}\). By gradually increasing Co concentration in both digesters until 0.3–0.5 mg kg\(^{-1}\), VFA started to be consumed. At the end of test, the recovered digester with OLR 5 kg VS m\(^{-3}\) day\(^{-1}\) was running stably with 0.2 mg kg\(^{-1}\) Se and 0.3–0.5 mg kg\(^{-1}\) Co addition, with a pH of 7.8, IA/PA ratio 0.4, specific methane production (SMP) 0.47 standard temperature and pressure (STP) m\(^{3}\) CH\(_4\) kg\(^{-1}\) VS day\(^{-1}\), volumetric methane production (VMP) 2.37 STP m\(^{3}\) CH\(_4\) m\(^{-3}\) day\(^{-1}\), and VFA concentration less than 500 mg L\(^{-1}\). For further understanding effect of...
trace elements on VFA production, short-term trials were carried out to assess their function on VFA production. The results indicated that with accumulated VFA, supplementation of trace elements stimulated VFA production to a greater extent than that of VFA consumption.

Effect of organic loading rate on TE dosing strategy and digester performance was studied in 5 digesters, all of which had stable operation but different trace element addition histories. 1 pair digesters were run as control at OLR 5 kg VS m⁻³ day⁻¹ over the course of the experiment, another pair operated with gradually loading increase to 6, 7, 8 and 9 kg VS m⁻³ day⁻¹. A SMP of 0.46±0.02 STP m³ CH₄ kg⁻¹ VS day⁻¹ at OLR 8 kg VS m⁻³ day⁻¹ was achieved. Volatile solids destruction (VSD) rate were similar between OLR 5 and 8 kg VS m⁻³ day⁻¹, approximate 0.74–0.75, whereas it was lowered to 0.71–0.72 at OLR 9 kg VS m⁻³ day⁻¹.

Residual methane production (RBP) test results showed that biogas production of digestate from OLR 5 and 7 kg VS m⁻³ day⁻¹ were similar, whereas digestate from OLR 9 kg VS m⁻³ day⁻¹ generated more biogas than OLR 5 kg VS m⁻³ day⁻¹, indicating lower conversion efficiency was achieved in digester at OLR 9 kg VS m⁻³ day⁻¹. Nitrogen mass balance equations were developed to distinguish nitrogen distribution in digesters. It showed that microbial biomass density increased along with OLR increase, which in turn requires the strength increase of TE addition. Specific increase rate of biomass at OLR of 9 kg VS m⁻³ day⁻¹, however, was lower than that of 8 kg VS m⁻³ day⁻¹, reflecting the decrease in specific methane production and VS destruction rate. The results indicate that FW digester was able to operate at OLR 8 kg VS m⁻³ day⁻¹, without loss of performance when compared with OLR 5 kg VS m⁻³ day⁻¹. Loading 9 kg VS m⁻³ day⁻¹ was regarded as overloaded due to the lower hydrolysis and acidification efficiency. The fifth digester, in which same TE dosing was applied, was operated with random loading: daily loading between 2.5–7.5 kg VS m⁻³ day⁻¹ was randomly introduced but weekly average loading maintained at 5 kg VS m⁻³ day⁻¹.

Stable performance was observed in this digester with 2.27 STP m³ CH₄ m⁻³ day⁻¹ of 30-day rolling average VMP and 76% of VSD rate, VFA concentration less than 500 mg L⁻¹.

Further research on essential TE supplementation for stable FW digestion at high loading was carried out. All TE additions were ceased except 0.3 mg kg⁻¹ of Co and 0.2 mg kg⁻¹ of Se, in two pairs of digesters at loading 5 and 8 kg VS m⁻³ day⁻¹ respectively. VFA accumulation occurred in higher loading digesters, which finally failed. VFA fluctuated around 4000 mg L⁻¹ in digesters at OLR 5 kg VS m⁻³ day⁻¹, until the rest of trace elements in 11 full trace elements recipe reintroduced, VFA degraded quickly to below 1000 mg L⁻¹.

The research provided new insight on optimising essential TE supplementation to FW digestion, especially at moderate and high loading rates to ensure stable and high productive biogas production.

2 ADDITIONAL INFORMATION

2.1 Supervisory team

Dr Yue Zhang (main supervisor), Prof Charles Banks (co-supervisor)

2.2 Funding

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