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IMPROVED TRADE WASTE CO-DIGESTION

A TRIAL SHOWING THAT DIGESTION WITH RECUPERATIVE THICKENING IS EFFECTIVE TO REDUCE DIGESTER PROCESS INHIBITION RISKS AND IMPROVE FOG LOADING RATE IN MUNICIPAL DIGESTERS.

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ABSTRACT

Trade waste co-digestion in municipal treatment plants improves the sustainability and cost effectiveness of wastewater treatment. Recently we showed that integration of recuperative thickening can improve the treatment capacity of sludge digesters. Here we report on the use of recuperative thickening at commercial scale for effective co-digestion of primary sludge and dairy factory DAF (dissolved air flotation) sludge with high fat, oil and grease (FOG) content (10–20% dry matter content; > 60 % FOG in dry matter). We show that use of recuperative thickening achieves (i) increased FOG loading rates and biogas productivities; (ii) FOG waste digestion without digester process inhibition; (iii) tripled digester treatment capacity. The digester capacity increase with recuperative thickening was achieved at less than 35% of the installation costs for new digesters.

INTRODUCTION

The combined anaerobic digestion (co-digestion) of municipal biosolids and trade waste such as food residuals, industrial processing waste and grease trap waste is common in Europe and North America (US EPA, 2014).

Co-digestion of trade waste and food residuals allows to potentially provide up to 100% of the gas, heat and power requirements at municipal treatment plants (US EPA, 2014).

Trade waste materials with high fat, oil and grease (FOG) content are preferred because they result in low waste procurement costs and reduced transport costs, a high methane yield (up to about 1 Nm^3 methane/kg degradable volatile solids loaded), trade waste gate fee revenues and improved biogas quality. However, processing of the waste in municipal digesters is complicated by the inhibitory nature of the waste, its poor solubility in water, its propensity to form deposits on digester walls, and the increased risks of pipework blockages with fat deposits.

FOG trade waste co-digestion is often complicated by practical problems such as increased risks of digester souring, digester foaming and fat deposition on tank walls and pipework. Operation guidelines therefore recommend low FOG loading rates for co-digestion (0.5 kg FOG/m^3digester/day). The result is a limited digester gas production increase that can be achieved from co-digestion of waste with high FOG content (40–60% increase). We reported recently (Thiele, 2010; Thiele *et al*., 2014) more than doubled treatment capacities in municipal digesters through integration of recuperative thickening (RT) in the digester process (RT digesters). This increased solids digestion efficiency, hydraulic treatment capacity and biogas productivity (Thiele *et al.*, 2014).

Here we report on the use of municipal digesters with recuperative thickening for co-digestion of primary sludge and dairy factory DAF (dissolved air flotation) sludge with high fat, oil and grease (FOG) content (10–20% dry matter content; > 60% FOG in dry matter). By comparing the operational performance of two parallel sludge digesters at full scale – one with and one without recuperative thickening – we show that digestion with recuperative thickening (RT) is effective to reduce digester process inhibition risks and to improve the FOG loading rate in municipal digesters (loading rate improved to: 1–1.9 kg FOG/m^3digester/day). Good digester process stability was achieved with recuperative thickening at high COD loading rates and high FOG loading rates without digester stability issues, foaming issues, pipework blockage issues or mechanical problems.

PLANT AND EXPERIMENT DETAILS

Methodology/Process

FOG digester process stability, biogas production rate and trade waste conversion efficiencies to biogas were assessed over an operation period of three years in an operating municipal sludge digester plant in New Zealand (Palmerston North City Council, PNCC).

The test plant consisted of two parallel identical digester tanks (Figure 1 and Figure 4, 1,350m^3 working

Figure 1. Digester tank with mixing system.

volume each), a dedicated liquid trade waste reception (Figure 2, 60m^3 capacity) and one recuperative thickener (RT) plant (Figure 3, 25m^3 sludge/hour processing capacity). Both digesters had purpose-designed sludge mixing systems.

The digesters had been cleaned out prior to the tests. The digester temperature was maintained at 35–37°C. RT plant operation hours were typically eight h/day. Polymer dosing rates in the RT plant were around five kg polymer/t DS loaded.

Analytical Methods

The pH, total solids, alkalinity and volatile fatty acids (VFA) concentrations in the digesters were sampled twice weekly and were determined using standard laboratory methods.

DAF sludge samples were taken daily from the freshly delivered trade waste and analysed for their total solids content and pH. Digester 1 (D1) functioned as the control to monitor the daily gas production from the primary sludge component, and digester 2 (D2) was the co-digestion experiment plant to monitor the combined daily gas production from primary sludge and added trade waste.

Figure 2. DAF sludge waste reception.

The biogas composition was monitored by a gas analyser with confirmatory gas chromatographic analysis of the biogas. The biogas from the co-digester tank (D2) contained about 68% methane compared to 64% methane in the "control" digester (D1), which received primary sludge only. The biogas from both digesters was used for power generation in a gasmotor genset (700 KWel capacity).

The primary sludge-specific biogas yield (Nm^3 biogas/kg primary sludge volatile solids loaded) was determined during operation of the co-digestion plant without trade waste addition (two months of operation). The primary sludge-specific biogas production was then estimated daily from the metered primary sludge load, the primary sludge volatile solids content and the specific biogas yield of the primary sludge. The specific daily biogas production from trade waste (Nm^3 biogas/kg DAF sludge solids loaded) was determined by subtracting the estimated daily primary sludge-specific biogas production from the total biogas production of the combined co-digestion plant, and dividing the result by the solids load in the daily load of DAF sludge.

RESULTS AND DISCUSSION

Reliability of The Test Setup

The establishment of digester process performance parameters at full scale in an operating municipal treatment plant is challenging and requires carefully designed and controlled test conditions. The work reported here was achieved under well controlled conditions comparing a "control digester" (D1) with a "FOG digester with recuperative thickening" (D2). D2 was operated in parallel to D1 and with the same daily municipal primary sludge input as D1 and with additional input of trade waste (Table 1). The conceptual arrangement of the digester tanks used for the digester treatment capacity and performance tests is shown in Figure 4. The primary sludge (PS) load (primary sludge, 4% solids; 84% VS in TS; average 145m^3/day) was evenly split between both digesters. Digester D2 received additional DAF sludge with high FOG content DAF sludge from a local dairy factory (up to 100–120 kg FOG/m^3; up to 20% total solids (TS) content; 95% VSinTS; up to 15m^3/day).

The performance of both digesters was monitored at commercial scale for three years (2012–2014) in order to document the digestion process stabilising effect of recuperative thickening on commercial co-digestion of trade waste with high FOG content. Operation data show that the trade waste reception of the test plant (Figure 2) worked well (data not shown) and without blockage issues when receiving liquid dairy factory waste with high FOG content (occasionally up to 20% TS content; 70% FOG in dry matter).

Figure 3. Recuperative thickener (RT) plant.

The average COD content of the DAF sludge was estimated from grab samples as 2.7kg COD/kg TS with a range of 2.5–2.9 kg COD/kg TS.

The average solids content of the DAF sludge was 10–11% TS with a typical maximum of 14–15% TS. The daily trade waste load to digester D2 was highly variable (Table 1).

The average TS content in the DAF sludge monitored over a period of three months was 10.8 +/- 2.3% TS (mean +/- STD, n=58). The average pH of the DAF sludge deliveries was 4.5 +/- 0.23.

Typical FOG Loading Rates

Achieved average FOG loading rates in D2 with recuperative thickening were 0.7 kg FOG/m^3 digester/day in operation period 1 and 1.0 kg FOG/m^3 digester/day in period 2, with maximum FOG loading rates of up to 1.8–1.9 kg FOG/m^3 digester/day on work days (see Table 2).

This maximum FOG loading rate (Table 2) to D2 with recuperative thickening was about four times the FOG loading rate to D1 with primary sludge FOG constituents.

Process Stability At High FOG Loading Rates

The FOG digestion process with recuperative thickening was stable and robust (Figure 5). Process stability was achieved despite highly variable loads and maximum FOG loading rates of up to 1.8–1.9 kg FOG/m^3 digester/day (Table 2).

The volatile fatty acid (VFA) levels in digester D2 were low (24 +/- 20 mg VFA/L; n=80) and similar to the VFA levels found in the control digester, D1 (13 +/- 4 mg VFA/L; n=80). This demonstrated the good process stability at high FOG loading rates. Increased digester process instability at high FOG loading rates would have produced VFA levels in excess of 200 mg VFA/L. Despite highly variable daily DAF sludge loads (Figure 5), the daily gas production increase responded within four to six hours after the trade waste addition, confirming the robustness of the FOG digester process with recuperative thickening.

The solids residence time (SRT) in digester D2 was typically >30 days (18 days SRT in the control digester). The solids concentration in digester D2 sludge varied typically between 2.3% TS and 1.6%TS (Table 2), demonstrating the efficacy of the recuperative thickening under high loading rates with FOG. For comparison, the sludge solids concentration in the control digester D1 in the same period was 1.1 +/- 0.17 % TS (n=80).

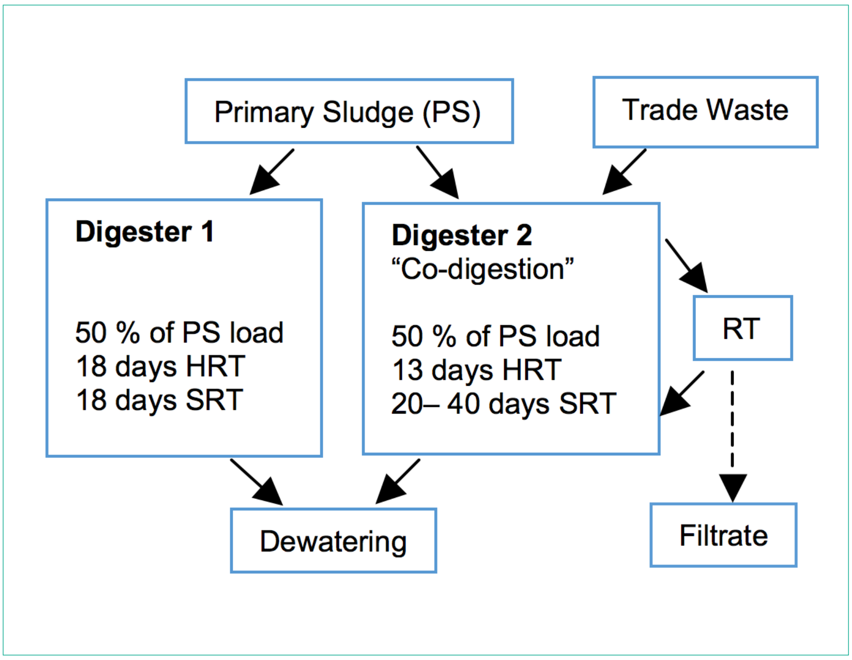

Figure 4. Process flow of the test plant.

Table 1. Summary of FOG loads during co-digestion of Fonterra factory DAF sludge + primary sludge from the PNCC treatment plant. Data shown are for the co-digestion (D2) and the control digester with primary sludge only (D1).

Category	Average trade waste load (kg FOG/day)	Maximum trade waste load (kg FOG/day)
D2, 2012	950	1,680
D2, 2014	650	1,850
D1, 2012 – 2014	0	0

Table 2. Maximum FOG loading rates. Data are shown for the co-digestion (D2) and the control digester with primary sludge (D1).

Category	Maximum daily trade waste load (kg FOG/day)	FOG loading rate (kg FOG/m^3 digester /day)
D2, 2012	2,280	1.8
D2, 2014	2,450	1.9
D1, 2012 - 2014	0	0.46

Process Resilience During COD Load Increase

The process resilience of mesophilic sludge digesters is indicated by four independent parameters: (a) the digester liquor pH; (b) the ratio of volatile fatty acids (VFA) to the alkalinity in the digester liquor (VFA/alkalinity ratio); (c) the biogas productivity (m^3biogas/m^3digester.day -1 and (d) the acceptable COD loading rate (kg COD/ m^3digester.day).

The data in Figure 5 demonstrate the rapid and proportionate biogas production response of D2 to peak daily FOG loading rates of up to 5.5kg FOG-COD/ m^3digester.day-1.

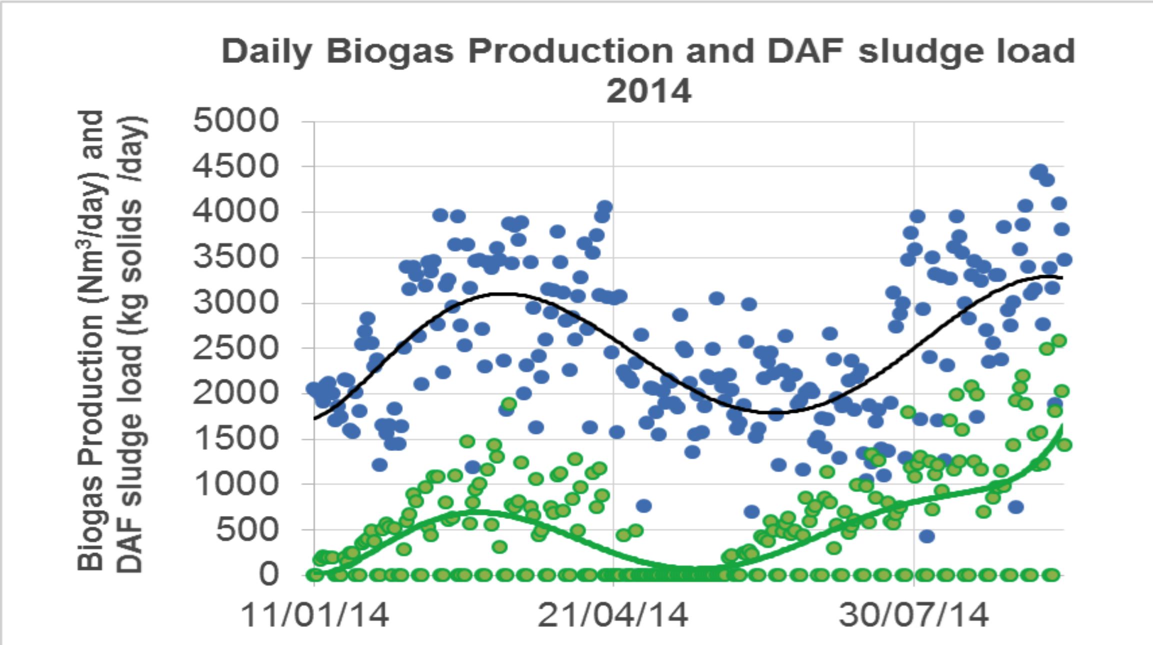

Figure 5. Total biogas flow (blue symbols) and trade waste solids load (green symbols).

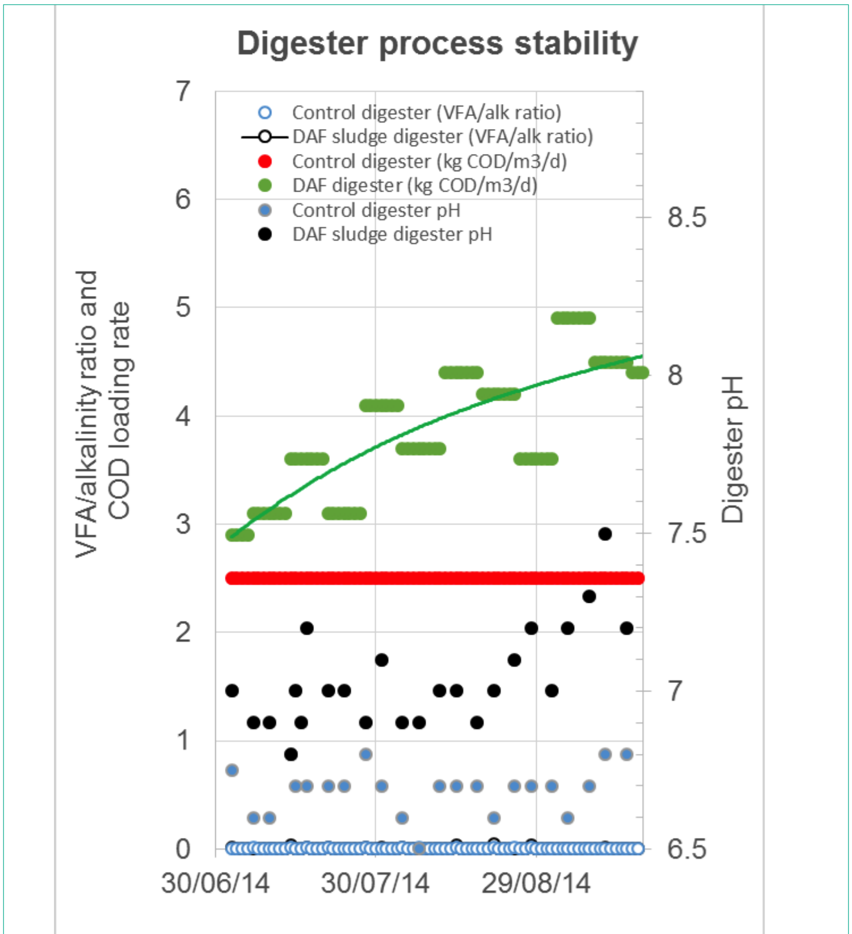

Figure 6. VFA/alkalinity ratio, pH and COD loading rate comparison in digesters D1 and D2.

On days with a total biogas production of 4,000–4,400m³.day-1 (Figure 5), the daily biogas production in digester D2 was 3,000–3,400m³.day-1. Based on the constructed working volume of 1,350m³, the biogas productivity of D2 was 2.2–2.5 m³biogas/m³digester.day -1 -, about 100–150% higher than the typical biogas productivity of standard municipal sludge digesters when operated with FOG co-digestion.

This significant improvement in the permissable loading rate and biogas production of digester D2 demonstrates the beneficial effect of recuperative thickening on the process stability in the digesters.

Figure 6 shows a comparison of the key digester process stability indicators in both digesters when operated side by side during a ramp-up of the FOG loading rate to digester D2. The key process stability indicators demonstrate that the digester process in D2 with recuperative thickening and very high COD loading rate was as stable as the digester process in digester D1 at low loading rates with primary sludge only. The VFA/alkalinity ratio in both digesters was very low and the pH was in the range of pH 7– 7.4.

Biogas Yields At High FOG Loading Rates

The average daily biogas production from primary sludge was about 1,000m3 per digester (Figure 5, January 2014 and May/June 2014). The average daily biogas production from FOG waste co-digestion was about 2,000–2,500m^3/day (digester D2 only).

Based on the biogas production from the added trade waste and its COD content, a 80–95% COD conversion efficiency of trade waste to methane was determined (Table 3).

Table 3. COD conversion efficiencies of DAF sludge COD to biogas. The average methane content of the biogas was estimated as 66%, the average biogas temperature as 30°C.

Parameter	Period 1 1/1/14–19/4/14 (108 days)	Period 2 1/8/14– 21/9/14 (51 days)
Biogas from primary sludge	217,296m^3	98,588m^3
Biogas from DAF sludge	68,824m^3	58,773m^3
DAF sludge solids load	47,407 kg TS	51,922 kg TS
DAF sludge COD conversion to methane	95%	80%

The data in Table 3 confirm that the digester process with recuperative thickening achieved a high COD conversion efficiency and a high biogas productivity, despite:

- A high COD loading rate;
- A highly variable daily COD loading pattern;
- The challenging nature of the loaded trade waste (60–70% FOG in dry matter);
- A high FOG loading rate – two to three times above industry guidelines for FOG digestion.

The biogas quality from D2 improved typically from 64% to about 68% methane when FOG waste was loaded. This was expected as the anaerobic digestion of trade waste with high FOG content typically produces a biogas with about 70 % methane content.

CONCLUSION

The operation of the PNCC municipal digesters with recuperative thickening has shown that anaerobic co-digestion of trade waste with high fat (FOG) content in mesophilic sludge digesters with recuperative thickening achieves:

- Tripled FOG loading rates and digester operation without sludge digester inhibition;
- More than tripled biogas productivities;
- Stable digester operation for three years without digester process inhibition or foaming;
- Tripled digester treatment capacity;
- Doubled capacity at less than 35% of installation costs for new digesters.

The sustained high FOG loading rates at the PNCC digesters with recuperative thickening were about four times the maximum FOG loading rate normally recommended in the industry (<0.5 kg FOG/m3 digester/day).

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