Executive summary

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Optimising Processes for the Stable Operation of Food Waste Digestion

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Co-investigators
Dr Yue Zhang and Dr Mark Walker

Grant holder
Professor Charles J Banks

School of Civil Engineering and the Environment
University of Southampton, Southampton SO17 1BJ
Tel 02380 594650 Fax 02380 677519 Email cjb@soton.ac.uk

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Previous research on the anaerobic digestion of source segregated food waste and operational results from commercial digesters have highlighted potential problems with the stable digestion of this material. When operating on this substrate the digestion process typically has a high ammonia concentration and elevated levels of volatile fatty acids (VFA), which can bring about acidification and failure of the digester if the buffering capacity is overcome. It was postulated that the relationship between ammonia and the elevated VFA levels resulted from toxicity to the acetoclastic methanogen population, further complicated by impairment of the function of autotrophic methanogens by trace element deficiency. The research presented explores the possibility of regulating the metabolic pathways leading to methane production under high ammonia concentrations by trace element supplementation and also the possibility of removing ammonia to reduce toxicity to the acetoclastic methanogens

Trace element analysis of digestate from food waste digesters operating at high ammonia concentration and food waste co-digesters operating at low ammonia concentrations showed very little difference in trace element composition. This confirmed that food waste could meet the trace element requirement for stable digestion provided that there was no ammonia toxicity. At high ammonia concentrations the accumulation of intermediate volatile fatty acids indicated that trace elements necessary to support an ammonia-inhibited methanogenic population were likely to be deficient in the food waste used in previous research. To validate if this was likely to be a widespread problem, representative samples of source segregated food waste were taken two waste collection schemes: one in Luton, South Bedfordshire and the other in Hackney, London. The physicochemical characteristics of these two food waste samples were analysed, including biochemical composition and trace elements. No clear difference in the key parameters was seen between the two waste streams and the Ludlow food waste, which had been used in the earlier projects.

Batch flask experiments were carried out to determine whether high concentrations of VFA in food waste digestate could be reduced by the addition of trace elements. The results showed that although trace elements could increase the rate of VFA destruction in a digester suffering long-term accumulation, they could not initiate this process. It was concluded that a period of non-feeding was a pre-requisite to the initiation of VFA removal, probably to allow time for changes in the microbial population to occur. The result highlighted that any strategy for stable food waste digestion should focus on the prevention of initial VFA accumulation in the digester by trace element supplementation, rather than on recovery of severely VFA-laden digesters. Further batch flask trials showed that in digestate from food waste digesters where VFA had not yet accumulated to very high levels the trace element selenium was essential in promoting VFA removal under high ammonia concentrations, and that cobalt and molybdenum may also be important but not necessarily essential. Experiments showed that at selenium concentrations greater than 0.4 mg l^{-1} the beneficial effects were not improved and at concentrations greater than 1.5 mgl^{-1} toxicity was observed.

In semi-continuous trials the results showed that if a proper trace element supplementation strategy was followed food waste could be digested stably at an organic loading rate (OLR) of 5 kg VS m^{-3} d^{-1} over an experimental period of around 100 days (2.5 retention times) without any VFA accumulation: a much higher loading than achieved in previous laboratory and full-scale trials. The VFA concentration in the pair of digesters supplemented with Se, Mo, Co and W and in the pair of digesters with full trace element supplementation remained below 200 mg l^{-1} up until the time the project was completed. In these digesters the volumetric biogas production reached 3.8 STP m^3 m^{-3} d^{-1} and the specific biogas production was still stable at 0.76 STP m^3 kg^{-1} VS at the OLR of 5 kg VS m^{-3} d^{-1}.

It can be concluded from the experimental results that selenium and cobalt are the key elements that are essential for long-term stability and are not present in sufficient

quantities in food waste. The minimum concentrations recommended for selenium and cobalt in food waste digesters at moderate organic loading rates are around 0.16 and 0.22 mg l^{-1} respectively. A total selenium concentration greater than 1.5 mg l^{-1} is likely to be toxic to the microbial consortium in the digester. Mo, W, and Ni are present in food waste in sufficient quantities for moderate loadings, but may have to be supplemented in digestion at a high organic loading rate. The potential for synergistic effects involving Mo and W has yet to be clarified. Food waste has sufficient Al, B, Cu, Fe, Mn and Zn.

FISH analysis of the methanogenic population found in the food waste digesters operating under high ammonia concentrations showed it to be comprised almost exclusively of members of the order *Methanomicrobiales*. This group of methanogens metabolise by the autotrophic route combining H_2 and CO_2 to form CH_4. Very few methanogens that are known to use the acetoclastic route to CH_4 production were found in the digestate. This result confirmed the initial hypothesis that ammonia caused selective inhibition of the methanogenic population.

For ammonia removal from digestate, gas stripping was chosen as the most suitable method of reducing or eliminating toxicity to acetoclastic methanogens and allowing stable digestion. The process configurations considered were: 1) *in situ* removal, where the ammonia is stripped continuously in the digester using a modified gas mixing system; 2) side-stream removal, where digestate is removed from the main digestion tank to a separate stripping process and returned to the digester; 3) post-hydrolysis removal, where ammonia is first released by a short anaerobic hydrolysis process and then removed prior to adding the waste to the main digester; 4) post-digestion ammonia removal carried out in conjunction with pasteurisation. The experimental work was designed to allow assessment of these four options and to generate data that could be used in a predictive model.

Batch experiments were carried out to investigate the kinetics of ammonia removal with respect to temperature, pH and gas flow rate. Increase in value of any one or a combination of these parameters had a positive effect on the removal rate of ammonia. At 35 and 55 °C ammonia removal timescales were in the order of 600 hours, whereas at 70 °C this could be reduced to around 15-17 hours at an appropriate gas flow rate. With pH adjustment timescales could be further reduced to around 4 hours at 70˚C. High VFA concentrations were shown to have a negative impact on the ammonia removal process as these led to a pH swing that prevented further stripping. This has implications for recovery of anaerobic digestion plants where the process is already operating at increased VFA concentrations, as it may limit the effectiveness of ammonia removal by biogas stripping.

In addition to these batch experiments, two semi-continuous digestion studies were performed to provide data on the integration of ammonia stripping with anaerobic digestion. These were the trial of a side-stream stripping process used in conjunction with mesophilic anaerobic digestion of food waste, and a study to quantify the ammonia release kinetics during a short hydrolysis process.

Under the experimental conditions used the side-stream process was not successful in preventing VFA accumulation, and this in turn limited the effectiveness of the ammonia removal process. A more extensive programme of experimentation is needed to optimise the system, particularly in order to maintain low ammonia concentrations in the initial stages. The stripping process should also be used in conjunction with trace element supplementation to prevent VFA accumulation.

The second experiment showed that the hydrolysis process configuration was not feasible without pH control, as only a small proportion (~15%) of the bio-available ammonia was released during this stage, and there was evidence to indicate that further hydrolysis/fermentation was inhibited.

To further the research, a model was developed using data from the batch stripping experiments to allow simulation of the ammonia concentration in an integrated anaerobic digestion and ammonia stripping process. The outcomes of the modelling suggest that *in situ* mesophilic stripping combined with gas mixing will lead to the lowest in-digester ammonia concentrations. A more thorough analysis of energy requirements is needed, however, and the best practice may be situation specific depending on the availability of waste heat.