Modelling of food waste digestion using ADM1 integrated with Aspen Plus

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1 THESIS ABSTRACT

The aim of this research was to produce an integrated modelling platform in which an anaerobic digester could be linked to the other unit operations which serve it, both in maintaining the physical-chemical conditions in the digester and in transforming the digestion products to useful fuel and nutrient sources. Within these system boundaries an accurate mass and energy balance could be determined and further optimised, particularly where the desired energy products are a mix of heat, power, and biomethane. The anaerobic digestion of food waste was chosen as the subject of the research because of its growing popularity and the availability of validation data.

Like many other organic substrates, food waste is potentially a good source of renewable energy in the form of biogas through anaerobic digestion. A number of experimental studies have, however, reported difficulties in the digestion of this material which may limit the applicability of the process. These arise from the complexity of the biochemical processes and the interaction between the microbial groups that make up the anaerobic community. When using food waste there is a tendency to accumulate intermediate volatile fatty acid products, and in particular propionic acid, which eventually causes the pH to drop and the digester to fail. Two factors are important in understanding and explaining the changes in the biochemical process that leads to this condition. The first is due to the differential in sensitivity to free ammonia of the two biochemical pathways that lead to methane formation. The acetoclastic methanogenic route is inhibited at a lower concentration than the hydrogenotrophic route, and methane formation therefore occurs almost exclusively via acetate oxidation to CO$_2$ and H$_2$ at high free ammonia concentrations. The accumulation of propionic acid is thought to be because formate, a product of its degradation, cannot be converted to CO$_2$ and H$_2$ as the necessary trace elements to build a formate dehydrogenase enzyme complex are missing.

The Anaerobic Digestion Model No. 1 (ADM1) was modified to reflect ammonia inhibition of acetoclastic methanogenesis and an acetate oxidation pathway was added. A further modification was included which allowed a ‘metabolic switch’ to operate in the model based on the availability of key trace elements. This operated through the H$_2$ feedback inhibition route rather than creating a new set of equations to consider formate oxidation in its own right: the end result is, however, identical in modelling terms. With these two modifications ADM1 could simulate experimental observations from food waste digesters where the total ammonia nitrogen (TAN) concentration exceeded 4 gN l$^{-1}$. Under these conditions acetate accumulation is first seen, followed by propionate accumulation, but with the subsequent decrease in acetate until a critical pH is reached. The ADM1 model was implemented in MATLAB with these modifications incorporated.

The second part of the research developed an energy model which linked ADM1 to the mechanical processes for biogas upgrading, Combined Heat and Power (CHP) production, and the digester mixing system. The energy model components were developed in the framework of the Aspen Plus modelling platform, with sub-units for processes not available in the standard Aspen Package being developed in Fortran, MS Excel or using the Aspen Simulation Workbook (ASW). This integration of the process components allows accurate sizing of the CHP and direct heating units required for an anaerobic digestion plant designed for fuel-grade methane production.

Based on the established model and its sub-modules, a number of case studies were developed. To this end the modified ADM1 was applied to mesophilic digestion of Sugar Beet Pulp to observe how the modified ADM1 responded to different substrate types. Secondly, to assess the capability of adding further mechanical processes the model was used to integrate and optimise single stage biogas upgrading. Finally, the digestion of food waste in the
municipal solid waste stream of urban areas in Vietnam was considered.

2 CONCLUSIONS

Within the general area of modelling, there has been no existing adequate tool for prediction of the behaviour of food waste digesters nor of the mass and energy balance of food waste digestion systems. This work, hence, carried out a number of tasks to produce an integrated modelling platform in which an anaerobic digestion process can be linked to other units of a biogas plant for accurate mass and energy balances.

- Development and delivery of a platform (MATLAB/Simulink® and Excel) of the ADM1 model for a CSTR system, which is flexible and adjustable and could also be applied to the anaerobic digestion of different types of organic substrates. Base on the platform, modified version of ADM1 model was developed to include the syntrophic acetate oxidation pathway for methanogenesis under elevated TAN concentrations and the role of trace elements in nurturing stability during the digestion process.

- Establishment of a biogas system in Aspen Plus which integrates the modified ADM1 model for accurate simulation of biogas plant operations in terms of mass and energy balance.

- Establishment of an ammonia stripping model in Aspen Plus which integrates the modified ADM1 model and the Aspen Simulation Workbook (ASW) to allow optimisation/control of the ammonia concentration in food waste digesters.

3 ADDITIONAL INFORMATION

3.1 Publications


- Simulation and optimisation of single stage biogas upgrading and bottling system using Aspen Plus. *International Conference on Anaerobic Digestion (Biogas Science)*, Austria, 2014

3.2 Supervisory team

Prof. Charles Banks and Dr. Sonia Heaven

3.3 Funding

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