CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Rapid acid released from carbohydrate-rich organic solid such as food waste and market waste, facing in the beginning stage of the fermentation process obstructed degradation of slowly degradable matters. This fact is attributed to the heterogeneous characteristics of these substrates and indicates the important of acid stress problem. The concept of inhibitory products control focusing on total VFA and their undissociated forms was here highlighted and explored. How to remove and avoid of these inhibition products needs to be taken into account. The objectives of this work were (1) to improve the acidogenesis condition for treating food waste and market waste with parallel control of the level of undissociated VFAs and (2) to find out the performance of waste bioconversion and gas production by using a two phase process. The feasibility of product inhibition control by pH adjustment and leachate dilution in the treatment of high solid food waste was also conducted. The results showed that the undissociated acid might be a useful parameter for monitoring the reactor stress; therefore, the VFA analysis should include the determination of the concentration of total organic acids and their undissociated fractions encountered during the start-up. The threshold inhibition of methanogenesis by undissociated acid using food and market wastes as feedstocks presented here was lower than in the literatures; this result emphasizes the importance of controlling TVA and undissociated VFA level to maintain a desired performance.

5.1.1 Anaerobic Digestion of Food Waste

The acidogenic phase of anaerobic digestion of food waste could be improved by pH adjustment. The production of VFA in the hydrolysis-acidification was enhanced by operation at neutral pH. The TVA concentration at pH 7 (neutral) was higher, from 1 to 1.5 times, than those observed at pH 5 and pH 6. The pH adjustment, either by neutral pH control or stepwise pH adjustment, proved to be an efficient way to control the inhibitory product, undissociated VFA. Most notably, a more than 9-to 56-fold reduction of undissociated acid was achieved by the neutral pH operations (14-95 mg/l) compared to pH 6 (146-1,080 mg/l) and pH 5 (1,065-11,222 mg/l). The stepwise increasing pH showed almost the same pattern as seen in neutral pH. It alleviated a rapid VFA build-up and extended the acidification; however, this process requires a longer fermentation time. Uncontrolled-pH led to the generation of a poor effluent both in terms of yield and the rate of SCOD and TVA, due to insufficient alkalinity, which suggested the need for supplemental alkalinity for resistance to pH change when treating food waste.

The technique of leachate dilution was used under the assumption of more acid production at low VFA concentration; however, this technique was shown to be inferior to the neutral pH adjustment in all aspects. The amount of total VFA increased by 73%, from 105.7 g HAc/kg VS (before dilution) to 183.3 g HAc/kg VS (after dilution). The first dilution performed the maximum efficiency control of an inhibitory undissociated VFA by providing, on average, a 75% reduction from its level prior to the dilution. By comparison, the dilution technique offered fewer advantages on hydrolysis-acidification improvement than the pH adjustment (neural range). This result suggested that the pH control was the key factor to initiate, operate and control the acidogenic phase. Further investigation revealed that applying the leachate dilution following the neutral pH control in the one stage reactor alleviated the acid stress problems and induced methanogenesis in a single-stage system, characterized by the high methane content (84%, max. value). Rapid onset of the methane phase by integrating the pH adjustment and the dilution technique offered the advantage of low digestion time, as well as a high load rate and small reactor space requirement.

This study revealed that the single stage digester was adequate for low solid food waste (with TS content 10%) by integrating pH adjustment technique as the main strategy for the enhancement acidogenesis and then supportive the methanogenesis with the dilution of leachate. The stepwise increasing pH method under single stage system offered the same advantage but the process was delayed.

Application of stepwise pH adjustment as product inhibition control technique for high solid food waste contributed to a substantial amount of VFA (285.2 g HAc/g VS,) with an extended VFA formation process. The failure to suppress undissociated acid of high solid waste by the neutral pH is probably related to relatively high acid released from high organic input. Failure to initiate the gas phase in the high acid digester could be overcome by coupling it with a methanogenic reactor in the two-phase system.

In two-phase system, the maximum allowable OLR achieved, in which 99% of COD removal was obtained, was 3.2 gCOD/l d. The coupling of the high acid reactor with methane production established a well balanced pH, total VFA and undissociated VFAs for the acid reactor and led to an improved methane phase performance. Food waste (15%TS) degraded into 35.1% CH_4, 16.9% CO_2, 26.2% soluble carbon with a remaining organic carbon (solid) of 7.1% by using product inhibition control technique and phase separation. With respect to the characteristics of food waste, known to be digested very rapidly, the two-phase system was more suitable to treat food waste than the one phase condition. In this study, although the wet system was able by dilute high solids to low TS, from around 25%TS to 10%TS, in the single stage condition, a larger reactor size was required to handle the diluted waste stream.

Keeping the pH neutral, inevitable and necessary to ensure stable methanognesis by addition of alkalinity, is costly both monetarily and in terms of the required operating energy. In the two phase system, the separation of biological processes has several drawbacks in regard to the number of reactors, with consequent capital and operating cost increases but it allowed for a smaller reactor size, shorter retention time as well as a higher loading rate. The effluent from the methanogenic reactor could be used for the dilution of acid effluent from the acidogenic reactor to maintain optimal pH for methanogenesis (operating-cost reduction). The present study thus suggested that periodic dilution of the leachate with methanogenic effluent in practice could improve the solubilization of the organic material contained in food waste. However, use of large amounts of dilution water on a periodic basis in full-scale application could result in high operation costs. Alternatively, the produced leachate could be continuously or semi-continuously fed to a high rate methanogenic reactor, such as a fixed film reactor, to convert the produced VFA into methane and prevent VFA build-up and inhibition of hydrolysis-acidogenesis in the acidogenic reactor. In summary, the stable anaerobic digestion of food waste with high organic solid can be realized through the appropriated start-up procedure by controlling TVA/undissociated acid with external buffer supplement and the utilization of the methanogenic effluent as dilution water with adequate time.

5.1.2 Anaerobic Digestion of Market Waste

The acidogenic phase of market waste digestion, focusing only on fruit and vegetable residues, was improved to obtain the maximum concentration of VFA. It was found that the acid-phase of market waste showed the best result when the pH at neutral level was controlled. The production of VFA was increased when the pH was high, which is due to the inactivation of extracellular enzymes at lower pH; pH 7 had a greater 1.7-to

3.0-fold increase in VFA generation rate by compared to pH 6 and pH 5. In addition, the neutral pH control extended hydrolysis-acidification. The acid yield of neutral pH adjustment was enhanced by 55-63% as compared to the reactors without control pH (dilution and control).

A high stable level of TVA in the neutral pH control treatment with the low methane composition (max. 9-15%CH_4) indicated the limitation of the AD process, regardless of the concentration of undissociated acid (below the threshold inhibition level of methanogenesis). However, it should be kept in mind that the neutral pH control may have led to the accumulation of VFAs that impaired the methanogenesis activity in acidogenic digesters and eventually upset the AD process. By contrast, under restricting conditions for methanogen activity, such as the high levels of undissociated VFA and a low pH, a higher methane concentration was recorded in the dilution experiment, with a maximum 31.8%CH_4. These findings revealed the strong influence of accumulated VFA inhibition on the AD process and mean that using only undissociated acid as an indicator of methanogenesis initiation can be misleading, especially for putrescible waste like market waste. One should bear in mind that using an extreme buffer addition causes a substantial increase in the VFA production as the fast hydrolysis/acidogenesis of readily biodegradable organic overwhelmed methanogenesis.

Market waste exhibited the classical waste decomposition pattern with a fast start-up phase beginning within 5-13 days, indicating the onset of easily digestible substrate limitation. A larger and faster VFA production stressed the validity of OLR for continuous one-stage systems. Imbalance between VFA production (1st-stage) and VFA utilization (2nd-stage) limited the performance of the single-phase digester in spite of additional alkalinity. A two-phase process ensures more suitable conditions for anaerobic digestion of market waste. Under these conditions, the market waste digestion reached 73% of VS reduction with high biogas generation in the methanogenic reactor, CH_4 accounting for 87% of the total biogas. Phase separation improved the methane yield. A yield of 0.30-l CH_4/g VS was obtained with the two-stage process compared with only 0.15-l CH_4/g VS in one-stage system. Although the consistent trend of CH_4 conversion efficiency was observed for one-phase digestion, the maximum CH_4 production occupied about 51% of total CH_4 recovery in the two-phase system with an operation time of 3 fold longer. The two-phase process was completed and a high level of cumulative methane production was achieved in 37 days. Moreover, the two-phase operation permitted a high conversion efficiency, since around 40% of the volatile matter was converted to the gas phase.

The two-phase system using a fixed film reactor for the methanogenic phase was able to withstand a high peak loading of 3.8 g COD/l d. Moreover, recycling of the methanoenic effluent saved buffering additives (one-phase 0.3 g $NaHCO_3$/g VS vs. two-phase 0.1 g $NaHCO_3$/g VS). Phase separation in the two-phase system is an advantage as it allows to use the acidogenic reactor as a methanogenic pocket after a certain period of time. Methanogenesis could proceed in the acidogenic reactor without coupling to the methanogenic reactor. As a consequence, the aciogenic reactor could be decoupled from methanogenic reactor and operated as one-stage process. In addition, the methanogenic reactor could be switched to treat the leachate coming from a second acid digester (in this study the fixed film reactor for market waste and food waste treatment was the same tank). The experiment carried out in this study could serve as guidance to design a continuous system that is more appropriate to treat a stream with large amounts of solid wastes. Batch treatment of fruit and vegetable market waste can be applied when small quantities are to be digested.

5.2 Recommendation for Further Study

To develop waste stabilization and methane production during the anaerobic digestion treatment of food waste and market waste, the following recommendations are given for further study.

5.2.1 Feasibility of inhibitory product control technique on treatment of food waste at high solid (20-25%TS) or mixed waste.

5.2.2 Study in the nutrient (nitrogen and phosphorus) content variation of the AD process

5.2.3 Analysis of microbial community and diversity in the anaerobic digestion of food waste and market waste