

Effluent recycling of a multiphase anaerobic baffled reactor treating food waste

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Abstract

A laboratory-scale multiphase anaerobic baffled reactor (MP-ABR) system was developed to enhance food waste (FW) bioconversion under mesophilic (35°C) conditions. The main objective of this study was to assess the impact of 100% effluent recycling back into the system. During the initial 90 days of operation, removal rates of COD_t, TS and VS were 75.32 ± 11.86%, 61.72 ± 9.36% and 69.62 ± 8.73% respectively. COD_s and VFA_t generated after the hydrolysis stage were removed up to 98.65 ± 0.51% and 97.54 ± 1.11% respectively. The average biogas yield of 141.1 mL/g-VS.d under 30 days hydraulic retention time (HRT) condition was obtained. The organic loading rate (OLR) was doubled for the subsequent 105 days of operation and the removal rates were found to be 88.95 ± 5.17%, 79.14 ± 5.81% and 87.12 ± 5.35% for COD_t, TS and VS respectively. The high removal rates of COD_s and VFA_t remained above 97% while the biogas yield was 102.11 mL/g-VS.d after doubling the OLR. The overall positive findings show the great potential of applying MP-ABR with “No effluent” for energy production from FW.

Keywords: food waste, anaerobic digestion, biogas, effluent recycling, anaerobic baffled reactor.

1 Introduction

Food waste (FW) management has been a growing challenge in urban cities like Singapore. As FW has a high energy potential, energy generation while reducing the waste seems ideal [1]. In most cases it has been found that biological



processes are more economic and efficient than physical/chemical treatment [2]. Among various methods available for organic waste management, anaerobic digestion (AD) appears to be a promising approach.

The multiphase anaerobic baffled reactor (MP-ABR) has been proposed taking into consideration the slow growth rate of different anaerobic microorganisms, particularly methanogens. An efficient reactor design must provide longer retention time of bacterial biomass within the reactor, together with good mixing to ensure a high rate of contact between the cells and their substrate [3]. The MP-ABR system serves the criterion, simultaneously isolating different microbial communities. Moreover, the ABR type of system has higher stability to organic and hydraulic shock loads, which can permit to control bacterial population [4]. The more significant advantage of the ABR is its ability to separate different phases of AD longitudinally down the reactor.

The recycling stream has three main purposes, which are, altering the pH of the incoming stream, diluting the incoming waste concentration, and also in certain cases helping to improve the conversion achieved in the reactor [3]. The main objective of this study is to evaluate the effect of 100% effluent recycling back into the MP-ABR system treating FW for complete utilization of the carbon source and comparing the performance with higher organic loading rate (OLR).

2 Materials and methods

2.1 Feed and inocula

Cooked FW (post-consumption) was collected from one of the local canteens in the university campus, which mainly composed of rice, noodles, meat and vegetables at the ratio 5:2.5:1.5:1 respectively. After removing the bones and the inorganic materials, the waste was homogenized using a kitchen blender. The seed sludge was from a local wastewater treatment plant that uses AD for sewage sludge treatment.

2.2 Reactor design and set-up

The MP-ABR system is a cuboidal four-compartment reactor comprising of alternating downflow and upflow sections separated by baffled plates. Each compartment was provided with overhead mixing unit rotating at 80-120 rpm to minimize dead zones and short circuiting. The sampling points were at the mid-level of each compartment and draining ports at the bottom. The reactor was connected to a gas flow meter and followed by a gas bag for gas sampling. The preliminary study on the MP-ABR reported the performance of the reactor design and successful phase separation process for FW treatment [5]. This study is a follow-up from the previous study where four different phases of the AD has been isolated in their respective four compartments N1, N2, N3, and N4. A settling tank was added in this study to separate the biomass from the effluent, eventually recycling back the supernatant with the feed and the settled biomass at the N4.



2.3 Operational parameters

The MP-ABR system was operated for a period of 195 days in two periods (90 days + 105 days) of operation at 35°C. FW mixed with the effluent was fed once a day throughout the experiment with OLR of 0.5-1 g/L and 1-2 g/L respectively during the two phases. An overall hydraulic retention time (HRT) of 30 days was maintained while the individual HRTs of each compartment were 6, 6, 9 and 9 days respectively. Samples from each compartment were withdrawn for analysis whenever needed. Total chemical oxygen demand (COD_t), soluble chemical oxygen demand (COD_s), total solids (TS), volatile solids (VS), volatile suspended solids (VSS), volatile fatty acids (VFA), pH and biogas volume and composition were measured regularly.

3 Results and discussion

3.1 Reactor performance in Period I (days 0–90)

The pH of all the compartments have gradually increased from their respective starting points indicating the buffering effect of the effluent recycling (Fig. 1). The concentration of COD_t increased from around 40 g/L during the first HRT to 60 g/L by the end of first period of operation (Fig. 2). Whereas the value for N2 was stable around 30 g/L and for N3 and N4 it was less than 20 g/L and 10 g/L respectively. The average COD_s concentrations of feed, N1, N2, N3 and N4 were 5.17, 13.92, 14.27, 7.28 and 0.19 g/L respectively. VS and VSS concentrations were highest in N1 that kept increasing constantly from 1-2.4% and 9-20 g/L respectively, while the rest of the compartments maintained in the same range all throughout the operation period.

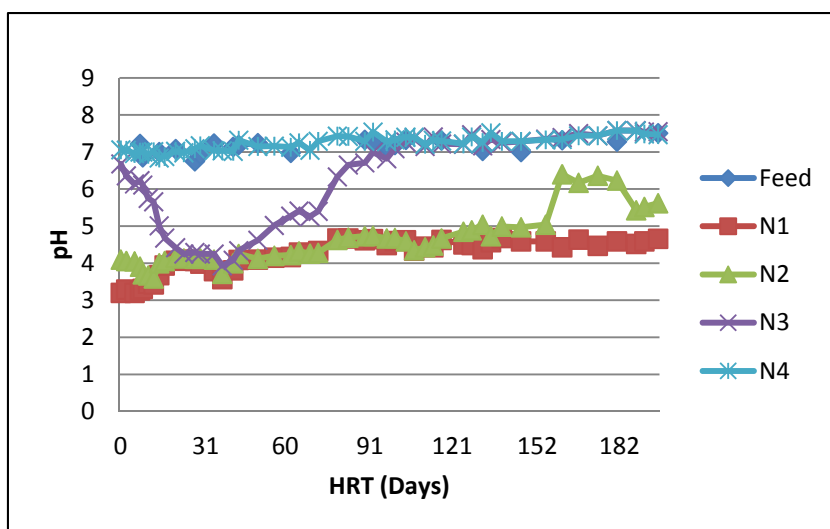


Figure 1: Variation of pH in different compartments of the MP-ABR.

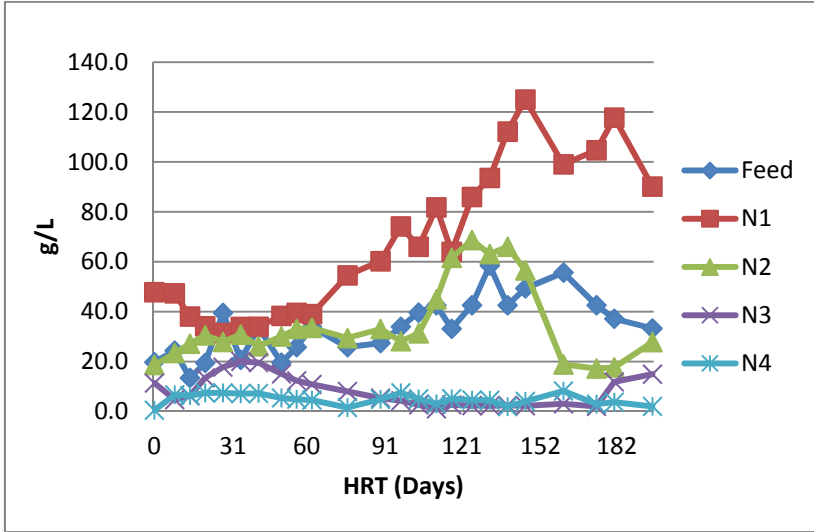


Figure 2: Concentration profile of COD_t in the MP-ABR.

3.2 Reactor performance in Period II (days 91-195)

Over the second period of operation the concentration of COD_t kept increasing continuously up until 120 g/L, which is 3 times higher than the starting point (Fig. 2). The reason could be mainly due to the doubling effect of OLR and the accumulation of most of the solids in the N1. While the concentration for N2 fluctuated between 20 and 60 g/L whereas N3 and N4 remained the same as before. The average COD_s concentrations of feed, N1, N2, N3 and N4 were 9.93, 18.94, 13.61, 0.66 and 0.28 g/L respectively. VS and VSS concentration kept accumulating in N1 reaching $3.42 \pm 0.32\%$ and 32.27 ± 2.17 g/L respectively between days 132–195.

3.3 VFA profile and overall comparison

The high concentration of VFAs in N2 and N3 in period I implies that the liquefied solubles from the acidogenesis are further broken down into short chain VFAs (Fig. 3). These VFAs act as the most simple substrate for the methanogens resulting rapid growth of methanogens and in biogas production. Though the growth of methanogens are not observed through the VS and COD_t concentrations, they were taking over the compartment N3 in second period of operation overshadowing the acetogens that were present initially leading the phase towards a neutral pH. Additionally, during the final HRT (days 160–195), pH of the N2 was also affected after the stabilization of N3. This suggests the abundance in the growth of methanogens overcoming the acidification effects imparted by high OLR. The trend of pH and growth of methanogens imply that the reactor can take in higher OLRs supporting the advantages of ABR type of system reported previously [3, 4]. Another reason could be due to the

accumulation of $\text{NH}_4^+\text{-N}$ in the system, which neutralises the VFAs in the acidogenic phase [6]. Additionally, it is also important to find the optimal point to sustain the different phases without leading to reactor failure either by complete acidogenesis or methanogenesis.

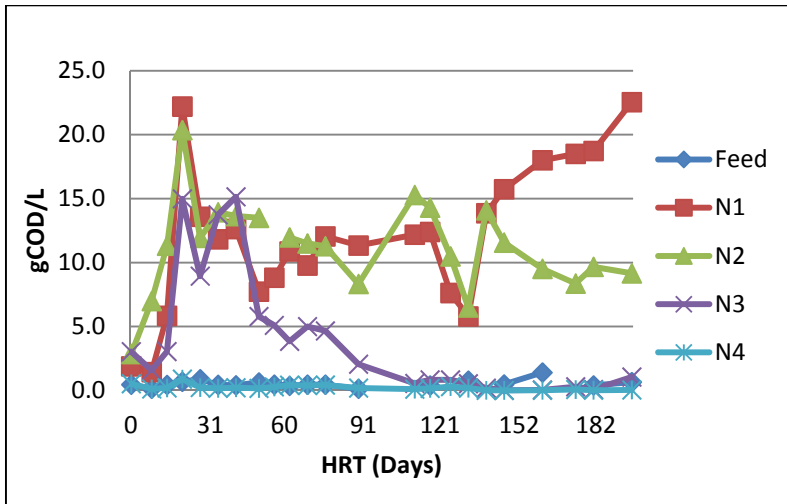


Figure 3: Concentration profile of VFA in the MP-ABR.

High removal rates were observed throughout the experiment. The removal rates of COD_t , TS and VS were 77.18 ± 13.01 , 65.00 ± 12.56 and 72.32 ± 11.03 respectively for period I and 88.95 ± 5.17 , 79.14 ± 5.81 and 87.12 ± 5.35 respectively for period II. The soluble component removal rates were calculated from the highest concentration point, which is after the hydrolysis stage. The removal rates of COD_s and VFA by the methanogenic phase of the reactor were 98.63 ± 0.51 and 96.21 ± 1.11 for period I and 98.52 ± 0.71 and 99.02 ± 1.08 for period II. The biogas production $141.09 \text{ mL/g-VS}_{\text{removed,d}}$ for period I and $102.11 \text{ mL/g-VS}_{\text{removed,d}}$ for period II of which 51–57% was methane.

Overall on comparing the performances in two periods, the performance in the period II was better than the period I in terms of removal rates. This can be attributed to the assimilation of the system towards effluent recycle and to the growth of methanogens during the period II that effected in better removal. However, the biogas production per VS consumed has slightly decreased. The possible reasons could be 1) the carbon was taken by methanogens for growth than getting converted to biogas, or 2) due to ammonia inhibition.

4 Conclusion

In conclusion, the performance of the MP-ABR system was not affected very much by 100% effluent recycling. Whereas on the other hand 'no effluent' means that the sludge retention time leading close to infinity which is considered

as one of the greatest benefits of this system. Future study will be focussed on an attempt to optimise the reactor stability between different phases of the process by optimising the feed concentration and to achieve better energy recovery and complete utilization of the FW for sustainable operation.

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