PREDICTING THE PERFORMANCE OF A CONTINUOUS ANAEROBIC DIGESTER FROM BATCH-SCALE LABORATORY STUDIES

N. QAMARUZ-ZAMAN, M. MILKE

Department of Civil and Natural Resources Engineering, University of Canterbury, New Zealand

ABSTRACT

Evaluation of the suitability of food wastes for anaerobic digestion is made difficult because of variable and uncertain degradation parameters. The purpose of the research was to examine the correspondence of first-order rate constants between laboratory testing of batch and continuous-feed systems. The feedstock for the experiments was a food waste developed to simulate residential collection. Batch tests were conducted using 120 g of food waste with 1.5 L of digested sewage sludge as inoculum. Continuous feed tests were conducted in 30 L digesters with daily feed/wasting and a hydraulic retention time of 30 days. Methane production was fit to a first-order rate equation with a resulting 0.22 d^{-1} rate over 13 reactors. The overall fitted methane yield for batch tests varied greatly from 0.15 to 0.56 L CH_4/g VS, although no signs of souring were seen. The inferred rate constant for the continuous tests were 0.09 d^{-1} when using only the yield data from the 8 of 13 tests above 0.35, and 0.3 when using all data. The results indicate broad similarity in rate constants between the two systems. They also indicate that a large number of batch tests are needed, and researchers should be reluctant to remove non-souring batch test results when fitting parameters.

1 INTRODUCTION

Anaerobic treatment plants are at risk of being poorly operated and perform inadequately if they are designed on the basis of poor laboratory or pilot-scale tests. Typical tests would provide empirically derived information on biogas yield, biogas kinetics, along with chemical oxygen demand (COD) and volatile solids (VS) reduction data. Kinetic studies offer insight into the rate of hydrolysis the effects of different pre-treatments, and the prediction of bioconversion and effluent quality. First order kinetics, due to its simplicity, was used to model the degradation of food waste under both batch (or tubes) and continuous systems. Bench or pilot-scale continuous reactor (CSTR) systems are a closer match to a full-scale continuous treatment project than batch tests and so might be expected to give different estimates of kinetic parameters.

2 METHODS

The research was conducted with a mixed food waste typical for urban residential collection systems. The waste was made in batches, blended, frozen, and then defrosted before use. The theoretical methane yield was roughly 0.45 L CH_4/g VS. The batch tests reported here were conducted with 120 wet g of food waste and 1.5 L of acclimated secondary mesophilic sewage digester effluent, operated at 35 C. The continuous systems were 30 L stainless steel digesters loaded at 1.5 and 3.0 g VS/L-day, a hydraulic retention of 30 days, and run at 35 C.

Digested sewage sludge (DSS) from the Christchurch Wastewater Treatment Plant was the seed for all set-ups. Non-linear regression with the function Solver in Microsoft Excel was used to best fit curves with respect to the experimental data. This function minimises the sum of squared differences (SSR) between observed and predicted values to estimate values of the model parameters: B-- cumulative methane at time t (L CH4/g VS), B0—ultimate methane yield (L CH4/g VS), and k-- first order rate constant (d-1).

3 RESULTS

The batch tests showed typical first-order decay dynamics, although a lag time of up to 1 day was often seen. The batch tests exhibited considerable sample-to-sample variability. Over the 13 batch tests, the fitted total yield had a mean of 0.35 L CH_4/g VS, with a standard deviation of 0.13. Some of the results are shown below in Figure 1. None of the batch tests had signs of souring (see Table 1). The lack of attainment of theoretical methane is expected to be due to oxidation of organic matter with oxygen or sulphate, due to unavailability of some cellulose by lignin-binding, or due to inhibition. The first-order decay constants (when also fitting a lag time parameters) had a mean of 0.22 day^{-1} with a standard deviation of 0.12. These rates are similar to those found by other researchers, for example, Neves et al. (2008) report first-order rate constants of 0.12 – 0.28 day^{-1} for batch tests of restaurant waste.

The continuous reactors were operated over 40 days and exhibited steady-state conditions sufficient to justify estimation of kinetic parameters (see Figure 2). The methane yield at 1.5 g VS/L-day was 0.31 L CH_4/g VS, while at 3.0 it was 0.32. To estimate a first-order decay constant for continuous feed reactors, one must assume a total potential yield, which would typically be found by batch tests conducted before bench-scale continuous operation. Considering that the continuous reactor accepted a variety of food waste batches, we believe it would be appropriate to use the average yield found with thirteen, 120 g aliquots of food waste in the batch tests, or 0.35 L CH_4/g VS, while the theoretical value of 0.45 would be an upper bound. The first-order degradation constant using 0.35 is 0.29 day^{-1}, while when using 0.45 it is 0.08, bracketing the constant of 0.22 day^{-1} found with the batch tests. Angelidaki and Sanders (2004) waste batches, we believe it would be appropriate to use the average yield found with thirteen, 120 g aliquots of food waste in the batch tests, or 0.35 L CH_4/g VS, while the theoretical value of 0.45 would be an upper bound. The first-order degradation constant using 0.35 is

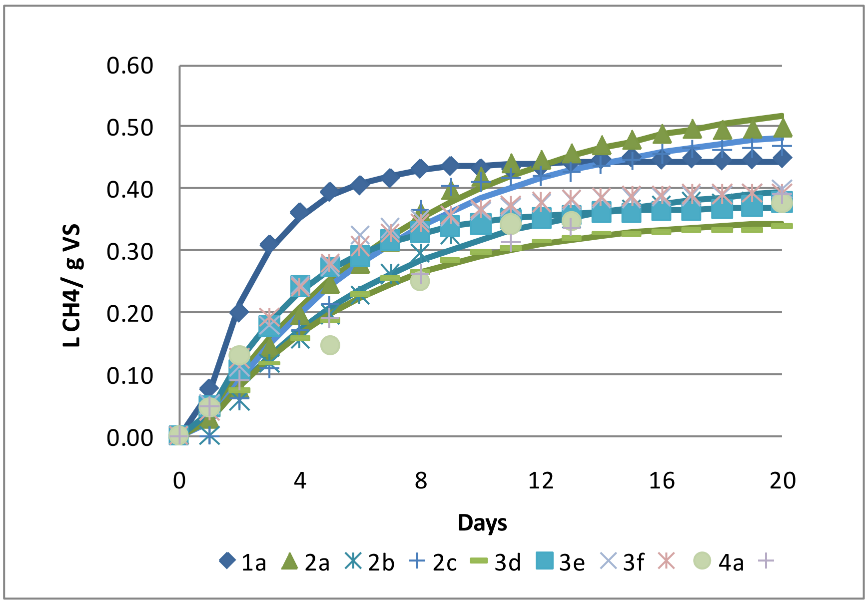

Figure 1: Methane yield of batch digestion of food waste with yields above 70% of theoretical. Symbols represent yields from experiments while the corresponding lines are yields fitted using first-order kinetics. Gas production by seed blanks has been removed.

Table 1: Chemical analyses at end of batch food waste tests. Notes: [a] Similar tubes that were tested at Day 2 had 2635 mg/l TVFA, at Day 5 = 1059 mg/l and at Day 13 had VFA < 696 mg/l. [b] Indicates the time reactor incubation is completed and samples taken for the ammonia, SCOD, alkalinity and VFA tests. Highlighted cells represent tests that achieved less than 70% of theoretical yield.

Test	SNH_3-N (mg/l)	SCOD (mg/l)	Alkalinity (mg/l)	TVFA[a] (mg/l)	pH	Day[b]
1a	1650	1450	5700	n/a	7.5	20
3a	1105	< 100	6700	n/a	7.3	20
3b	1343	325	5700	< 696	7.4	40
3c	1160	1550	4800	n/a	7.5	27
3d	1368	1325	4500	< 696	7.4	62
3e	1220	1750	6000	< 696	7.0	56
3f	1313	1725	4800	< 696	7.4	62

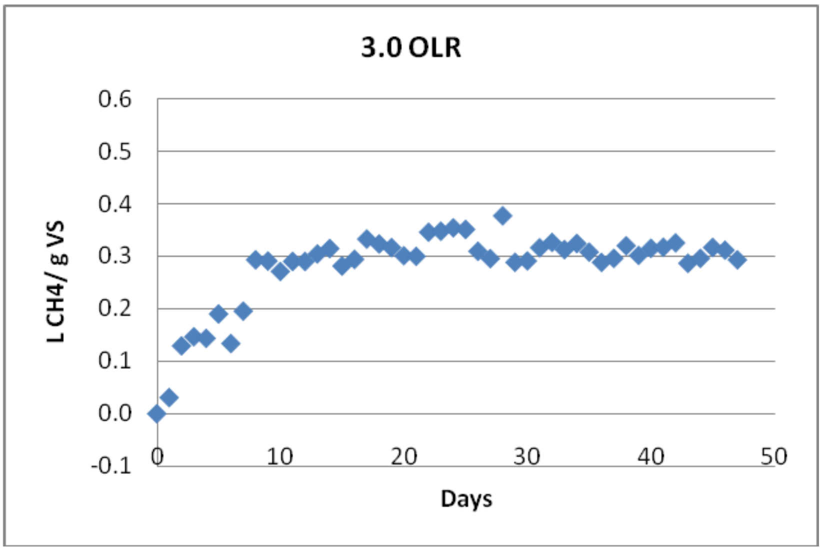

Figure 2: Methane yield of continuous reactor for feed of 3 g VS/L-day food waste, 30 days HRT at 35 C.

0.29 day^{-1}, while when using 0.45 it is 0.08, bracketing the constant of 0.22 day^{-1} found with the batch tests. Angelidaki and Sanders (2004) concluded that the use of theoretical yields to estimate first-order degradation constants can lead to difficulties, and recommended the use of practical maximum yields, supporting the notion that in this study an observed value of 0.35 would be more appropriate than a theoretical value of 0.45.

4 CONCLUSIONS

The results indicate that the batch tests provide an adequate representation of first-order degradation kinetics, and that little extra information is gained from bench-scale testing of a continuous system. Further study of the effect of the time lag is needed. Our conclusion is that the bench-scale continuous testing of food waste digestion can be skipped, and that testing can move from batch, bench-scale tests (with sufficient mass to ensure relative sample-to-sample homogeneity) to pilot-scale (roughly 1000 L) tests.

REFERENCES

Angelidaki, I., and Sanders, W. (2004). Assessment of the anaerobic biodegradability of macropollutants. Reviews in Environmental Science and Technology, 3: 117-129.

Neves, L., et al. (2008). Influence of composition on the biomethanation potential of restaurant waste at mesophilic temperatures. Waste Management, 28: 965-972.