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Abstract

Experiments were conducted with vegetables (Potato, Carrot, Spinach), fruits (Grapes, Orange) and cooked oil collected from restaurants, in 6 litre laboratory reactors operated in batch mode with organic loading rate ranging from 1.0 – 6.0 g·[VS]/l. The kinetics of biogas production under the co-digestion was studied using first order exponential, Fitzhugh and Cone model. The goodness of models fit to the observed data was first checked by calculating the Pearson product-moment correlation coefficient. A matrix of p-values for testing the hypothesis of no correlation was also determined. Results showed that all models perform well comparatively with the observed data. Estimated degradation rate constants were similar for the vegetables and fruits co-digestion but different in the case of the co-digestion with oil.

Keywords

Anaerobic co-digestion, kinetic models, Pearson correlation

Introduction

The easy biodegradable organic matter content of Fruits and Vegetable Wastes (FVW) with high moisture facilitates their biological treatment and shows the trend of these wastes for anaerobic digestion [1]. Fruit and vegetable waste have a high ratio of volatile solids to total solids (86 -92%) and have a very interesting methane potential. The anaerobic digestion of fruit and vegetable waste from a vegetable market in Tunis was experimented [2]. Among the co-digested wastes, one of the most commonly used is lipids. Lipids, characterized either as fats or oils and greases, are one of the major organic matters found in food wastes and some industrial wastewaters, such as those coming from slaughterhouses, dairy industries or fat refineries, restaurants. Co-digestion is one of the advantages of anaerobic digestion process because several wastes having complimentary characteristics can be treated in a single process [3]. This paper organises experimental results obtained through co-digestion of fruits, vegetables and oil in batch operations.

Materials and Methods

Reactor and rector operation conditions

A hundred (100) days experiments were carried out in double-walled glass reactors of 6-L effective volume, maintained at 35 °C by a regulated water bath. Mixing in the reactors was done by a system of magnetic stirring. The pH, biogas and methane production was measured on-line. The reactor was seeded at a volatile suspended solids concentration (VSS) of around 6 g VSS/L with anaerobic sludge taken from an industrial-scale anaerobic UASB reactor treating the effluents from a sugar refinery. The reactors were operated at batch mode.

Materials and Methods

Characterisation of Substrate

The type of vegetables, Potato, Carrot and Spinach, vegetable substrates were collected from the Al Mawaleh central vegetable market, Muscat, Oman. Cooked oil sample where collected from the restaurants. The vegetables were shredded into small pieces ± 2 cm and used for characterization as well for feeding. The vegetable substrates were stored at 4ºC. The characterization of raw substrates was carried out in triplicate. The results are shown in Table 1.

Table 1 Characteristic of Substrates

Parameters	Cooked oil	Potato	Carrot	Spinach
Total Solids [g/g]	0.1	0.33	0.17	0.12
Volatile Solids [g/g]	0.10	0.26	0.14	0.10
pH	7.2 ± 0.50	7.0 ± 0.50	7.3 ± 0.50	7.2 ± 0.50
$COD_{soluble}$ [mg/l]	2.10	2.20	1.80	0.90

Results and Discussion

Biogas production

The Organic Loading Rate (OLR) for vegetable substrate was varied from 4 – 6 g VS/l along with a constant volume of 5 ml of oil. The oil volume was not varied, since oil degradation was taking more time. Addition of oil increased the gas flow rate to 425 ml/hr at an OLR of 6 g VSS/l. Further the OLR for vegetable substrate was increased to 7 g VSS/l keeping the oil addition as 5 ml, but there was no significant influence on the gas flow rate and the total gas volume produced. The Chemical Oxygen Demand (COD) accumulation in the reactor was not very high compared to the number of total experiments days (100 days) for which the reactor was operated. There were minor variations which was almost constant.

Bio-methane yield

The methane yield for combined vegetable substrates were 325 ml CH4/g·VS and the degradation kinetics was 0.03 g·[VS]/g·[VS]·d, which is similar to the individual vegetable substrates. The methane yield for co-digestion of vegetable, fruit and oil substrate was more, 780 ml CH4/g·[VS] and the degradation kinetics was 0.08 g [VS]/g·[VS]·d. Co-digestion had high degradation rate compared to the degradation rate of fat when used as a single substrate. This may be due to the fact that vegetables and fruits had readily degradable carbon material.

Kinetic models

Experimental, exponential, Fitzhugh and Cone models were used to fit the measured biogas production. The domain for all the models is $t \geq 0$. Model parameters were estimated using nlinfit function in Matlab software (R2011a) [4]. To compare the models, Pearson coefficients (Rsqrd) were calculated.

Table 2 Calculated parameters for three models

Model	Parameter	Vegetables	Fruits	Co-digestion
Exponential	***k***	0.017906	0.046694	0.061563
	Rsqrd	0.99554	0.99585	0.99505
Cone	***k***	0.025563	0.03642	0.089259
	Rsqrd	0.9977	0.99453	0.99892
Fitzhugh	***k***	0.018664	0.021544	0.024738
	Rsqrd	0.99554	0.99585	0.99505

$$Bp = P_0(1 - \exp(-kt))$$ Exponential

$$Bp = P_0 (1 - \exp(-kt)^n)$$ Fitzhugh

$$Bp = \frac{P_0}{1 + (kt)^{-n}}$$ Cone

'Bp' Biogas production in each batch ml/g VS, 'P_0' is the final biogas yield, 'k' is the rate constant1/day,'t' is the batch duration (degradation time in hours), 'n' is the shape factor, dimensionless.

The models fit with experimental values are shown in Fig. 2. The experimental data and the model data with three models estimated have best fit. The degradation time was more in case of vegetables than the fruit substrate and for co-digestion. The degradation constant 'k' remained constant for vegetable substrate for all the three models. Fitzhugh model has shown constant value of 'k' for all the three substrates. The parameters calculated are shown in table 2.

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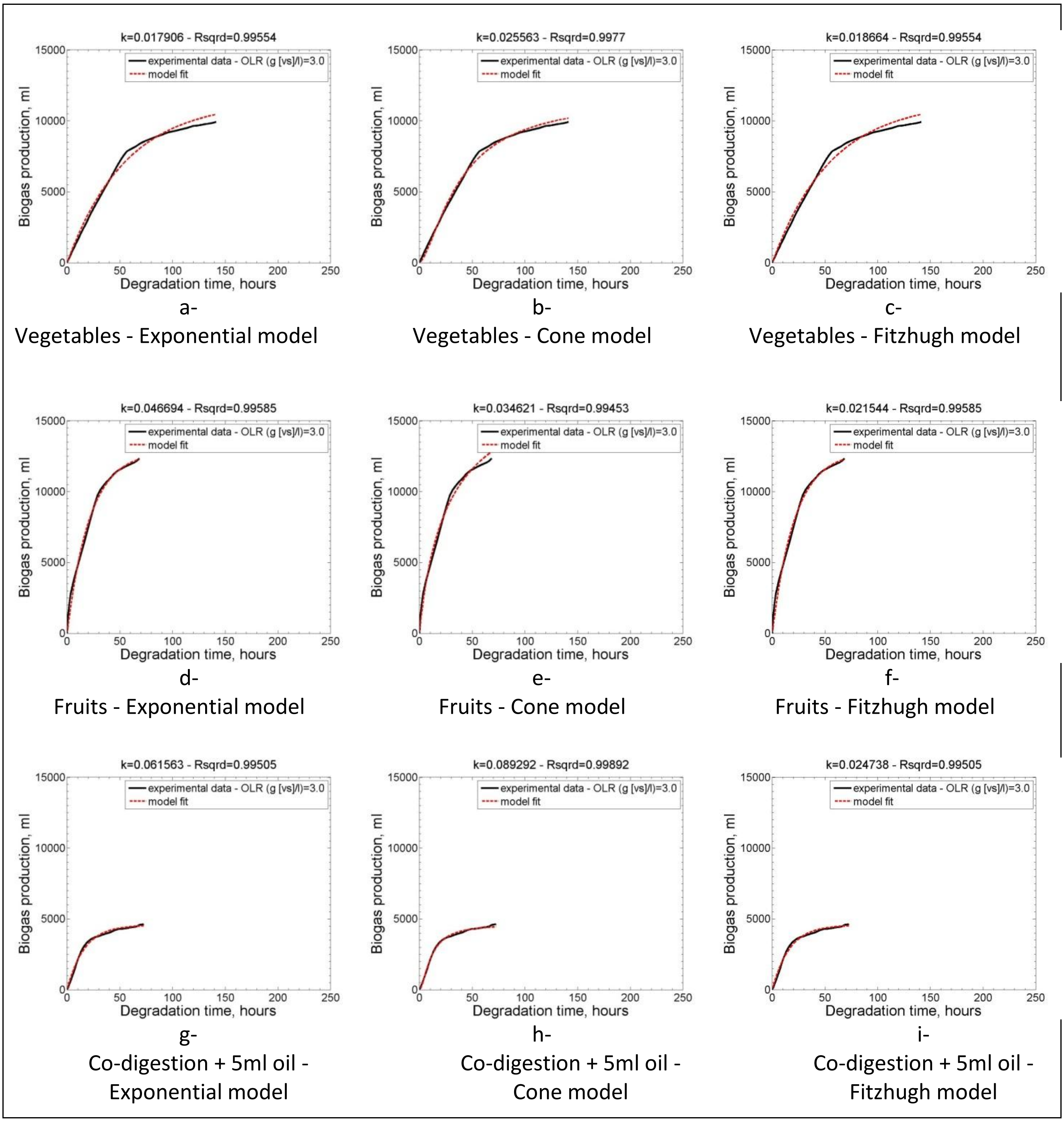

Figure 2. Experimental and model fit a), b) and c) vegetable substrates d), e) and f) fruit substrates g), h) and i) co-digestion of vegetable, fruit and oil substrates

REFERENCES

[1] H Bouallagui, R Ben Cheikh, L Marouani, M Hamdi. "Mesopholic biogas production from fruit and vegetable waste in a tubular digester." *Bioresour.Technol*. vol. 86, pp. 85–89, 2003.

[2] H Bouallagui, Y Touhami, R Ben Cheikh, M Hamdi. "Bioreactors performance used in anaerobic digestion of fruit and vegetable wastes: review." *Process Biochem*. vol. 40, pp. 989–995, 2005.

[3] A Ferna´ndez, A Sa´nchez, X Font. "Anaerobic co-digestion of a simulated organic fraction of municipal solid wastes and fats of animal and vegetable origin." *Biochem. Eng. J*. vol. 26, pp. 22–28, 2005.

[4] Hamed M. El-Mashad. "Kinetics of methane production from the codigestion of switchgrass and *Spirulina algae*." *Bioresource Technology*. Vol. 132, pp 305-312, 2013.