Anaerobic Co-Digestion of Vegetable Waste and Cooked Oil in Anaerobic Sequencing Batch Reactor (ASBR)

J V Thanikal, M. Torrijos, S M Rizwan, Hatem Yazidi, R. Senthil Kumar, and Philipe Sousbie

***Abstract*—**The anaerobic co-digestion process, which can be defined as the simultaneous treatment of two or more organic biodegradable waste streams by anaerobic digestion, offers great potential for the proper disposal of the organic fraction of solid waste coming from source or separate collection systems. A case study conducted at central vegetable and fruit market at Muscat, Oman, reveals that an amount of 5-6 tonnes of waste is generated per day. The cooked oil from restaurant is currently disposed to the central drain. Anaerobic digestion of a mixture of fruit and cooked oil was studied, using anaerobic sequencing batch reactors operated at mesophilic temperature. Biodegradability study was carried out for both vegetable and oil substrates individually. Co-digestion of vegetable substrate with cooked oil shows an increase in biogas production of 30%.

***Keywords*—**Anaerobic digestion, ASBR, cooked oil, co-digestion, vegetable substrate.

I. Introduction

THE central fruit and vegetable market at Al Mawaleh, Muscat, and Sultanate of Oman produces a large quantity of waste. A survey was conducted for a period of one year covering all seasons to estimate the waste generated. The survey indicated that a mixed quantity of fruit and vegetable waste of 5-6 tonnes is generated per day. It is quite a common problem of disposal of cooked oil from the restaurant and it is often observed that they are discharged to common sewers that interfere with the common effluent treatment plants. Currently the fruit and vegetable waste are sent to the dumpsite at the interior parts of the city. Anaerobic digestion is a well-established process for treating many types of organic wastes, both solid and liquid [1], [2], [3], [4], [5], [6].

The easy biodegradable organic matter content of FVW with high moisture facilitates their biological treatment and shows the trend of these wastes for anaerobic digestion [7]. 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 [8]. 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 [9]. The objectives of this work are (i) to study the anaerobic biodegradability of vegetable and oil fraction; (ii) to investigate the co-digestion of both the substrates at different organic loading; (iii) to explore the bio-methane potential.

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II. Materials and Methods

A. Reactor and rector operation conditions

The 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.

B. Analysis and parameters

Total solids (TS) suspended solids (SS) and volatile suspended solids (VSS) were measured according to the standard method (APHA, 1998). The pH was measured online using Metler Toledo pH probe Inpro 4260i. The biogas production was measured on-line every 2 minutes by Milligascounter MGC-1 flow meters (Ritter gas meters) fitted with a 4-20 mA output. The software supplied by Ritter was used to log the gas output. The samples were centrifuged and the COD soluble for the content inside the reactor was determined by spectrophotometry at 620 nm according to the HACH method (DRB-200, USA). The VFA was determined by titration method.

III. Results and Discussions

A. 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 4o C. The characterization of raw substrates was carried out in triplicate and the average composition was described as average ± standard deviation. The results are shown in Table 1.

TABLE I
CHARACTERISTIC OF SUBSTRATES

Parameters	Cooked oil	Potato	Carrot	Spinach
Total Solids (g/g)	0.10	0.33	0.17	0.12
Volatile Solids (g/g)	0.10	0.26	0.14	0.10
pH	7.2±0.50	7.2±0.50	7.3±0.50	7.2±0.50
COD $_{soluble}$ (mg/l)	2.10	2.20	1.80	0.90

B. Start-up of reactor

The laboratory scale reactor of effective volume 6 l, was operated under a controlled temperature of 35 ºC ±5 ºC. The reactor was initially fed with 4 batches of ethanol as direct carbon source to check the biodegradability of inoculum. The reactors were operated initially at a low OLR, One of the reactors was fed with vegetable substrate of OLR of 0.5 g· VSS/ l volume of reactor and another reactor with 1 ml of oil. The pH variation in the reactors was observed between 7.0 – 7.8 and the pH were almost constant throughout the experiments. After being studied the biodegradability, the reactors were batch fed with vegetable substrate of OLR 0.5 – 6.0 g·VSS/l volume of reactor. Further the reactor was then operated with vegetable substrate of OLR 6g VS/l, along with cooked oil fraction between 1-7ml. There was no accumulation of volatile fatty acid in the reactor throughout the experiment.

C. Biodegradability

Experiments were conducted to find the biodegradability of each of the substrate. The volume of biogas produced over time was monitored online making it possible to measure the total volume of biogas and the kinetics of biogas production for each batch. It was very difficult to mark the end of the cycle or batch, since the biogas production was low. It was difficult to differentiate the biogas produced during the endogenous phase. Towards the end of the batches, the biogas production rate became very low and a specific method was developed to find out the time when the sludge was back to its endogenous activity, that is to say the time when it could be assumed that the reaction was over and the organic matter added was eliminated. In this aim, a "biogas activity curve" was plotted with time for vegetable and oil substrate see figure 1&2. This curve is a kind of derivative with respect to the last available biogas flow rate measurement.

The biogas production rate by endogenous respiration was measured in the few hours following the end of the reaction time. It was assumed that endogenous activity was constant all over the batch and biogas production by endogenous respiration was removed from the total volume of biogas produced. The average specific kinetic of degradation was calculated by dividing the quantity of substrate added (in VSS) by the duration of the batch and by the volatile suspended solids (VSS) concentration in the reactor. This parameter was also measured when 80% of the total volume of biogas was produced. Several batches of experiments were conducted and fig. 1&2 represents the typical plot.

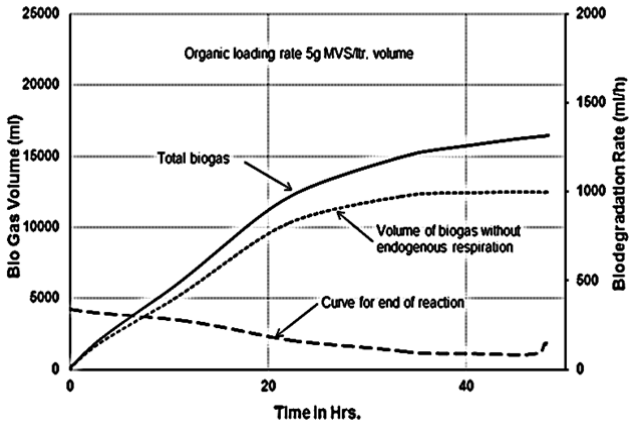

Fig. 1 Evolution over time of the volume of biogas produced, of the volume of biogas without endogenous respiration and of the curve used to identify the end of the reaction (biogas activity curve, vegetable substrate).

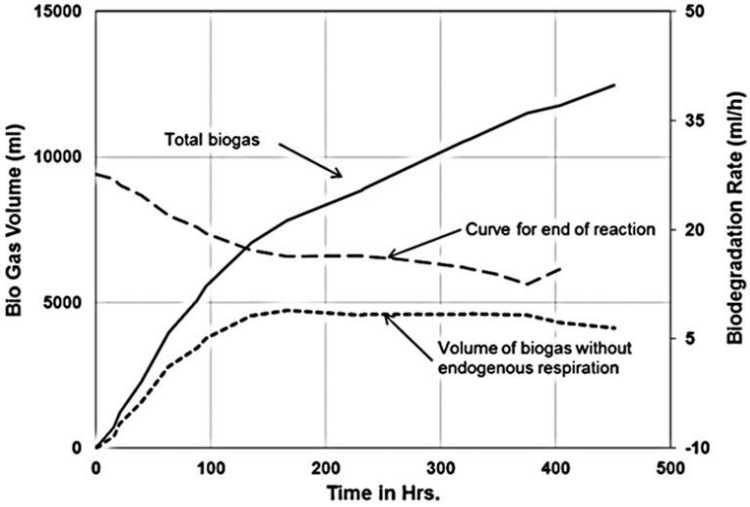

Fig. 2 Evolution over time of the volume of biogas produced, of the volume of biogas without endogenous respiration and of the curve used to identify the end of the reaction (biogas activity curve, oil substrate).

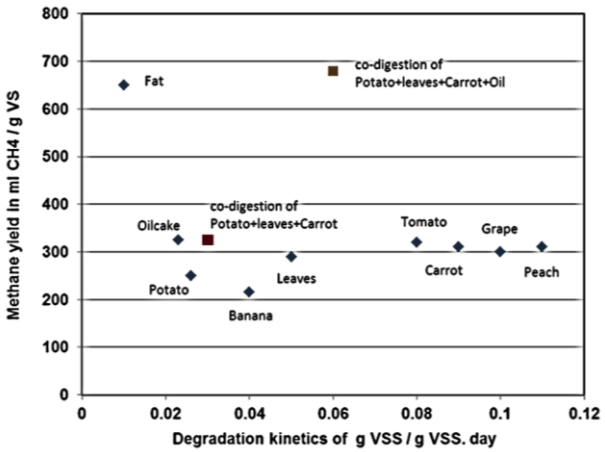

Fig. 3 Methane yield and degradation kinetics for the different substrates.

D. Analysis

Total solids (TS) and volatile suspended solids (VS) were measured according to the standard method (APHA, 1998). The pH was measured online using Metler Toledo pH probe Inpro 4260i. The biogas production was measured on-line every 2 minutes by Milligascounter MGC-1 flow meters (Ritter gas meters) fitted with a 4-20 mA output. The software supplied by Ritter was used to log the gas output. The samples were centrifuged and the $COD_{soluble}$ for the content inside the reactor was determined by spectrophotometry at 620 nm according to the HACH method (DRB-200, USA). The VFA was determined by titration method. Methane content in the biogas is measured using online methane analyser supplied by Bluesens, Germany. The table 2 summarises the reactor operation.

IV. Effect Of Substrate Addition On Biogas Production

A. Biogas production

The reactor was initially fed with different batches of vegetable substrates (carrot, potato, spinach) mixed together for different charges varying from 0.5 – 6.0 g VS/l. The sequence of batch feeding was once, twice, alternate days and daily in week (HRT 7-1 day). The biogas production varied from 200– 325 ml/hr for OLR of 0.5 – 6.0 g VS/l respectively, when fed in a daily batch mode. A similar operation was carried out with oil with a feed of 1-5 ml. It was observed that the maximum gas flow rate was 25 – 45ml/hr respectively. However it was noticed that the gas flow continued even after 200 hours indicating that the substrate was still not completely degraded. A co-digestion process was then carried out with vegetable substrates in combination with Oil. The 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 COD accumulation in the reactor was not very high compared to the number of days (100 days) for which the reactor was operated. There were minor variations which was almost constant.

B. Measurement of the Methane Yield and of the degradation kinetics of different substrates

The average specific reaction kinetics was evaluated at two different phases. The first phase was at the end of the reaction phase when the substrate was at endogenous respiration, and the second one, when 80 % of the reaction was completed. The results of the methane yield and of the kinetics at 80 % of the reaction are reported at figure 3 for combined vegetable substrates and co-digestion of combined vegetable substrates and oil. Figure 3 also shows degradation kinetics of other vegetable, fruits and fat substrates (experiments conducted at INRA-LBE, France). For fruits and vegetables the methane yields were all between 230 and 360 ml CH4/(g·VS) when used as individual substrates. However, the range of specific degradation kinetics was quite large with values in the range 0.03-0.1 (g·VS)/ (g·VS·d) 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 and oil substrate was more, 680 ml CH4/g·VS and the degradation kinetics was 0.06 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 had readily degradable carbon material.

V. Conclusion

This case study was carried out to know the potential degradation of vegetable substrate along with the residual oil substrate that appears to be waste from restaurants to look at the methane yield. The results were compared with similar studies done for different individual vegetable, fruit and fat substrates. The combined vegetable substrates remained in the same compartment as readily degradable material, whereas addition of oil shown an increased methane production with high degradation rate. The system proved to be stable at high OLR with constant pH and no accumulation of volatile fatty acids.

VI. Acknowledgement

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