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Anaerobic co-digestion of waste fruits and vegetables and swine manure in a pilot-scale bioreactor

V. N. Hubenov *, S. N. Mihaylova, I. S. Simeonov

The Stephan Angeloff Institute of Microbiology, Bulgarian Academy of Sciences
Acad. G. Bonchev, bl. 26, Sofia 1113, Bulgaria

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Anaerobic digestion (AD) of mixtures of different substrates is a new trend in biogas production. It gives possibilities to stimulate the AD of materials not easily susceptible to this process by mixing them with other substances which are easier degradable or to improve the content of compounds, C/N ratio and thus the process stability. In this study, swine manure (SM) and a specific mixture of waste fruits and vegetables (WFV) were used as single substrates and in a mixture at various ratios. The mixture of WFV was with a constant ratio of 40% waste potatoes (WP), 20% waste tomatoes (WT), 20% waste cucumbers (WC) and 20% waste apples (WA). The results showed that the increase of the WFV in the inlet organics mixture led to an increase of the specific daily biogas flow rate at a slight decrease of methane and small increase of the carbon dioxide content in the biogas obtained. The optimal mix ratio for co-digestion of SM and WFV maximizing the biogas and the methane yields obtained from a unit of biodegraded organics was found to be SM:WFV = 70:30. Under this conditions, the biogas and methane yields from a unit of degraded organics reached 1.090 m^3/kgVS.day and 0.65 m^3/kgVS.day, respectively. The co-digestion of SM and WFV not only improved the stability of the anaerobic process, but also led to a higher methane production.

Keywords: Anaerobic co-digestion, swine manure, waste fruits and vegetables, biogas, methane, biodegradation, optimum

INTRODUCTION

Anaerobic digestion (AD) is an effective biotechnological process for treating different agricultural, municipal and industrial wastes [1, 2, 3]. It combines environmental depollution (ecological aspect) with production of renewable energy – biogas, the main component of which is methane (energetical aspect).

Another ecological effect of AD is the reduction of methane (a strong greenhouse gas) emissions [4].

However, AD is a very unstable process in regard to the biogas reactor operation due to the complicated interactions between different microbial species, as well as to the complex transformations of the organic matter affected by a variety of environmental factors [5].

AD has been widely used for the biodegradation of cattle manure (CM), swine manure (SM), poultry litter (PL) and activated sludge (AS) from wastewater treatment plants. Traditionally, the process is a single substrate treatment [1, 2], but recently many authors reported that AS, CM and food waste can be used as main co-substrates in the anaerobic co-digestion of waste fruits and vegetables (WFV) [6, 7, 8, 9].

AD of mixtures of different substrates is a new trend in biogas production. It gives possibilities to stimulate the AD of materials not easily susceptible to this process by mixing them with other substances which are easier degradable. The other advantages of the co-digestion are in that potential inhibitor compounds can be diluted, nutrient balance can be improved and biogas yield increased [10].

WFV are produced in large quantities in markets in many big cities [10, 11, 12] and are inadequately treated by land application.

AD reduces the need of waste disposal and leads to the formation of biogas and digestate (potential manure). Our previous studies demonstrated good performances of AD of WFV and either CM or AS in mesophilic conditions [17, 20]. However, until now, very few studies have been carried out concerning the optimal ratio of different co-substrates [15, 16].

The aim of this paper was to study the anaerobic co-digestion of SM and a mixture of WFV at various ratios under mesophilic conditions in a pilot-scale continuously stirred-tank bioreactor in view of obtaining an optimal ratio for maximizing the methane production.

* To whom all correspondence should be sent: E-mail: vhubenov@microbio.bas.bg

MATERIALS AND METHODS

MATERIALS

Specificity and pretreatment of SM and WFV as substrates for AD

In this study, the substrates used for AD were SM and a mixture of WFV at various ratios. The mixture of WFV was at a constant ratio of 40% waste potatoes (WP), 20% waste tomatoes (WT), 20% waste cucumbers (WC) and 20% waste apples (WA). All components of the mixture of WFV were mixed with an appropriate amount of water, grinded with mixer and filtered through a coarse sieve. The SM was obtained from a little farm nearby Sofia. The WFV were collected from markets in Sofia. The material was homogenized in an electric blender. The samples were stored at 4°C in a refrigerator until usage.

The following parameters were determined using analytical methods: total solids (TS), volatile solids (VS), *pH*. Total biogas production and biogas composition (CH_4 and CO_2) were measured using appropriate devices.

Experimental setup (pilot-scale bioreactor)

The experiments were carried out in a 100-L pilot-scale continuously stirred-tank anaerobic bioreactor (ABR) with a working volume of 80 L in mesophilic conditions (34 ± 0.5°C) [24]. The ABR was operated in semi-continuous mode. The scheme of the pilot-scale ABR is shown on Fig. 1.

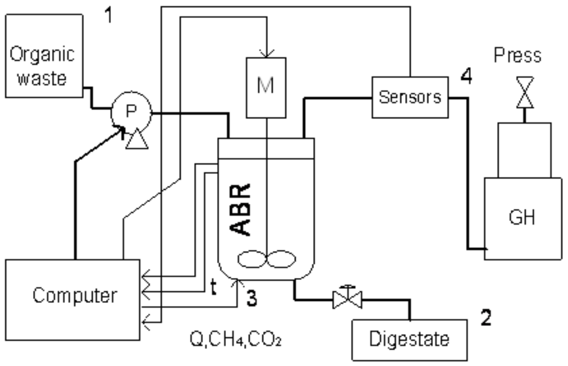


Fig. 1. Experimental setup of pilot scale ABR
1 – vessel for the influent (substrate); 2 – vessel for the effluent (digestate); 3 – heater control; 4 – sensors for Q, CH_4, CO_2, ABR – anaerobic bioreactor; GH – gas holder; M – AC drive of the stirrer; P – peristaltic or progressive cavity type pump, t – sensor for the temperature in the bioreactor; Press – sensor for the pressure in the bioreactor

The substrate (organic waste) was stored in a plastic can of 25 L placed in the influent line of the ABR. The digestate taken out of it during semi-continuous operation (feeding one to 24 times daily) was stored in a plastic can of 50 L in the next-door auxiliary service premises of the biogas plant.

A biogas outlet from the upper bioreactor flange led off the biogas to a 200 L metal gas holder (GH) operating on the water displacement principle (the inner vessel, placed in a vessel with water, is displaced vertically by the biogas).

The biogas flow rate was measured through transformation of the linear shift of the inlet vessel of the GH into normalized electrical signal (sensor developed by our team).

Samples for *pH* measurements and biochemical analyses were taken from the effluent of the bioreactor (digestate). Corrections of *pH* were done (if necessary) with additions of 2 N NaOH to the influent.

METHODS

Analytical methods

TS and VS. TS and VS were measured according to standard methods (APHA-AWWA-WPCF, 1985).

Biogas yield. Total biogas production was measured by the water displacement technique (graduated gas holder) and by a sensor developed by our team [24].

Biogas composition. The biogas composition was measured with computerized devices of MSR (Germany) with infrared sensors.

pH in the bioreactors was measured daily in the effluent with a laboratory *pH*-meter. *pH* of the influent was also measured daily.

Chemicals. All chemicals used were of analytical grade and were obtained from commercial sources.

Calculations

For comparison of data, some parameters were calculated according to the following formulas:

- degree of biodegradation (DBD):

$$DBD = \frac{VS_{\inf l} - VS_{effl}}{VS_{\inf l}}.100\,[\%],$$

where VS_{infl} and VS_{effl}, [g/L] are volatile solids, per 1 L of the working volume, of the influent and of the effluent, respectively;

- specific biogas production:

$$Q_{biogas}^{sp} = \frac{Q_{biogas}^{spV}}{VS_{effl}(t-1) - VS_{effl}(t) + VS_{\inf l}},$$

where Q_{biogas}^{sp} [dm^3 biogas/g VS.day] – specific flow rate of methane obtained from 1 L of the working volume of the bioreactor per 1 g biodegraded organics, per day;

- specific methane production:

$$Q_{CH_4}^{sp} = \frac{Q_{CH_4}^{spV}}{VS_{effl}(t-1) - VS_{effl}(t) + VS_{\inf l}},$$

where $Q_{CH_4}^{sp}$ [dm^3 CH_4/g VS.day] – specific flow rate of methane obtained from 1 L of the working volume of the bioreactor and from 1 g biodegraded organics; Q_{biogas}^{spV} and $Q_{CH_4}^{spV}$ - specific flow rate of biogas and methane, respectively, obtained from 1 L of the working volume of the bioreactor per day and were calculated as follows:

$$Q_{biogas}^{spV} = \frac{Q_{biogas}}{V_{work}}, \quad Q_{CH_4}^{spV} = \frac{Q_{CH_4}}{V_{work}}$$

RESULTS AND DISCUSSION

Startup

The startup of the ABR was done with SM using the natural microbial community in this substrate. After the start of the AD of SM, this process was stabilized as a continuous one with a dilution rate *D* = 0.025 day^{-1} in the next 60 days.

Experiments with mixtures of SM and WFV

After the stabilization of the continuous process of AD of SM with *D* = 0.025 day^{-1}, addition of WFV in various ratios was started as follows:

- co-digestion of SM and WFV in a ratio of 90:10 was started and stabilized during the next 30 days;
- the same was done for ratios SM:WFV = 70:30, 50:50 and 25:75;
- operation with AD of a mixture only of WFV was performed in the last phase of this experiment.

During the whole incubation period, the specific daily biogas flow rate Q_{biogas}^{spV} increased proportionally with the increase of WFV percentage in the feeding substrate. At the same time, there was a slight decrease in the CH_4 content and slight increase in the CO_2 content. These may have been due to the higher content of VS in the WFV mixture than in SM.

There was also an increase of the specific daily methane flow rate $Q_{CH_4}^{spV}$ despite the small increase of the CO_2 content in the biogas obtained.

The organic load of the pilot ABR, the average specific daily biogas and methane yields, as well as the degree of biodegradation for anaerobic co-digestion of mixtures with different ratio of SM and WFV and for D = 0.025 day^{-1} are presented in Table 1.

The maximal biogas yield from a unit of degraded organics in the anaerobic co-digestion of mixtures of SM and WFV was at a ratio SM:WFV = 70:30 with a value of 0.65 m^3/kgVS/day. This result is comparable with that obtained by Boualagui *et al.* [23] – biogas yield of 0.61 m^3/kgVS/day from a mixture of WFV and abattoir wastes at the ratio of 30:70.

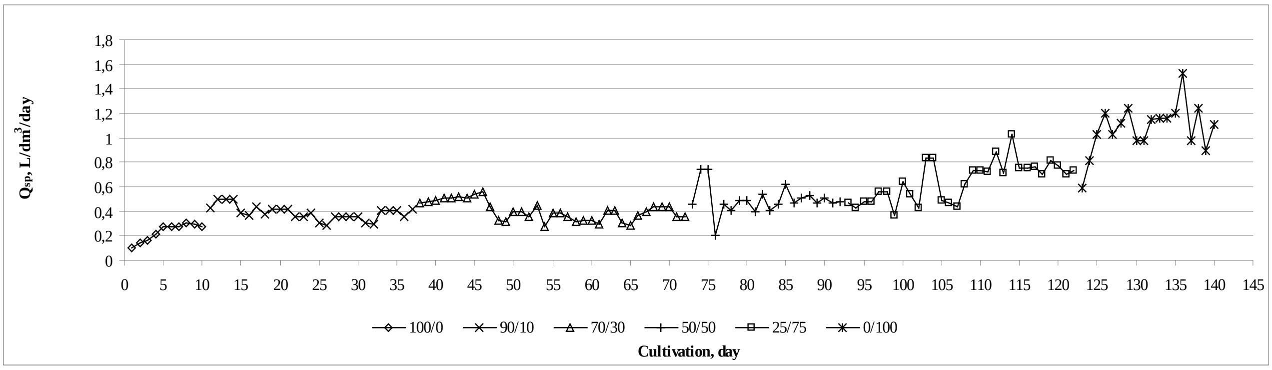
In our case the biogas yield was by 38.5% higher at this ratio in comparison with SM as a single substrate, and by 16.5% higher in comparison with WFV as a single substrate. In spite of the decrease of methane content in the biogas with the increase of WFV in the mixture, the yield of methane from unit degraded organics was maximal at the same ratio and was higher than the methane yields from WFV and SM as single substrates with 20.0 % and 35.4%, respectively.

Bouallagui *et al.* [23] reported 34.4 % higher methane yield for the mixture with the highest result than for the anaerobic digestion of WFV as a single substrate. The methane yield for WFV as a single substrate was about 0.52 m^3/kgVS/day which is higher than that for SM as a single substrate with 19.2%. Kafle *et al.* [24] considered that co-digestion of SM and apple waste at 67:33 ratio (bioreactor operated at continuous mode and HRT=30 days) leads to 16 % higher methane yield than AD of SM.

The degree of biodegradation at the optimal ratio with respect to biogas and methane yields (SM:WFV = 70:30), was lower, compared to the degree of pure substrates biodegradation (SM or WFV).

Table 1. Biodegradation, biogas and methane yield for different ratios of SM and WFV for D = 0.025 day^{-1}

Substrate	Organic load, kgVS/m^3. day	Biogas yield, m^3/kgVS.day	Content of CH_4, vol %	Yield of CH_4, m^3/kgVS.day	DBD, %
SM	0.446	0.67	62	0.42	72.3
90% SM + 10% WFV	0.500	0.726	61	0.44	50.3
70% SM + 30% WFV	0.466	1.090	60	0.65	60.3
50% SM + 50% WFV	0.970	0.536	59	0.32	70.6
25% SM+ 75% WFV	1.290	0.580	58	0.34	83.1
WFV	1.15	0.91	57	0.52	78.9



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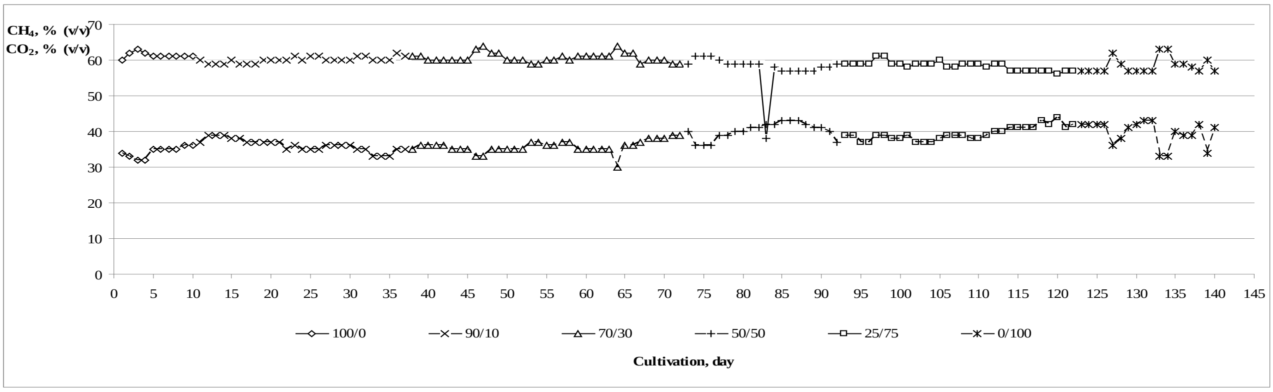

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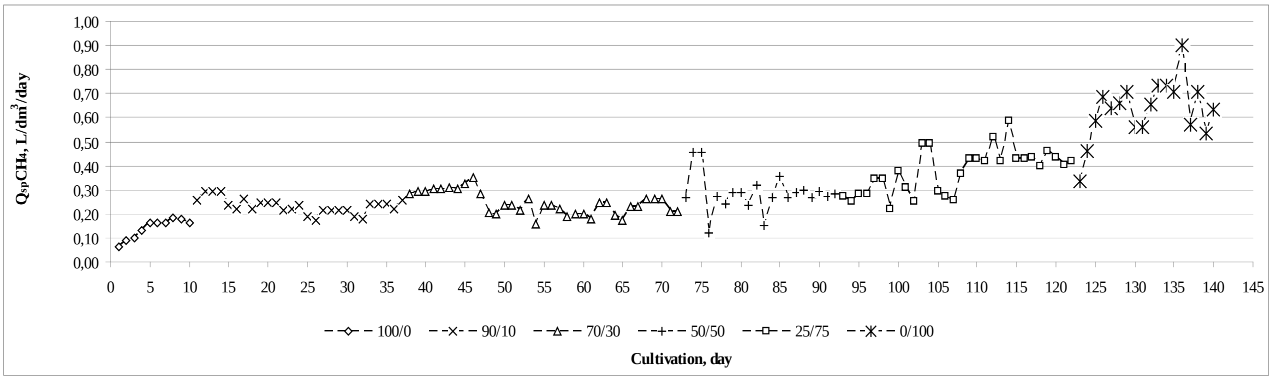

C

Fig. 2. A. Specific flow rate of biogas Q^{spV}_{biogas} [L/dm^3/day] for different ratios of SM and WFV in the substrate;

B. Content of methane and carbon dioxide in the biogas;

C. Specific flow rate of methane Q^{spV}_{CH4} [L/dm^3/day] for different ratios of SM and WFV in the substrate

CONCLUSION

Generation of methane gas from mixtures of SM and WFV is a stable and effective biomethanization process.

The optimal ratio for co-digestion of SM and WFV maximizing the biogas and the methane yields obtained from a unit of biodegraded organics was found to be SM:WFV = 70:30. Under this condition, the biogas and methane yields from a unit of degraded organics amounted to 1.090 m^3/kgVS.day and 0.65 m^3/kgVS.day, respectively. The co-digestion of SM and WFV not only improved the stability of the anaerobic process, but also led to a higher methane production.

However, the degree of biodegradation at that optimal ratio (DBD=60.3 %) was lower compared to the degree of single substrates biodegradation (DBD = 72.3 % for SM as a single substrate and DBD = 78.9 % for WFV as a single substrate).

These results were object of a utility model of the patent administration of the Republic of Bulgaria [25].

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АНАЕРОБНА БИОДЕГРАДАЦИЯ НА СМЕСИ ОТ ОТПАДНИ ПЛОДОВЕ И ЗЕЛЕНЧУЦИ И СВИНСКИ ТОР В ПИЛОТЕН БИОРЕАКТОР

В. Н. Хубенов *, С. Н. Михайлова, И. С. Симеонов

Институт по микробиология „Стефан Ангелов", Българска академия на науките
Ул. Акад.Г. Бончев, бл. 26, София 1113, България

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(Резюме)

Анаеробната биодеградация (АБД) на смеси от различни субстрати е нов подход при получаването на биогаз. Това дава възможност да се стимулира АБД на трудно разградими субстрати, чрез смесването им с други субстанции, които се поддават по-лесно на АБД или да се подобри състава, съотношението C/N и от там и стабилността на процеса. В настоящото изследване в качеството на субстрати бяха използвани свински тор (СТ) и специфична смес от отпадни плодове и зеленчуци (ОПЗ), както самостоятелно, така и под формата на смеси в различни съотношения. Сместа от ОПЗ беше с постоянно съотношение на отпадни картофи – 40%, отпадни домати – 20%, отпадни краставици – 20% и отпадни ябълки – 20%. Резултатите показват, че увеличаването на съдържанието на ОПЗ в подавания субстрат води до увеличаване и на специфичния добив на биогаз, паралелно със слабо понижение на CH_4 и малко повишаване на CO_2 в биогаза. Беше установено, че оптималното съотношение между свинския тор и ОПЗ, по отношение на получаване на максимален добив на биогаз и CH_4, е СТ:ОПЗ = 70:30. При тези условия добивите на биогаз и CH_4 от единица разградена органика достигаха съответно 1.090 м^3/кг.ден и 0.65 м^3/кг.ден. Съвместната АБД на СТ и ОПЗ не само подобрява стабилността на анаеробния процес, но води и до по-висока продукция на CH_4.