

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

4,800

Open access books available

122,000

International authors and editors

135M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.

For more information visit www.intechopen.com



Co-Digestion of Organic Waste and Sewage Sludge by Dry Batch Anaerobic Treatment

Beatrix Rózsáné Szűcs¹, Miklós Simon¹
and György Füleky²
¹Eötvös József College
²Szent István University
Hungary

1. Introduction

Organic waste and waste water sludges can be stabilized both in anaerobic and in aerobic processes. The advantage of the anaerobic treatment of the waste is that biogas develops during the degradation process. Instead of energy consumption which is a usual characteristic of aerobic-processes it is accompanied with energy production, which can be utilized as energy source (Kayhanian & Tchobanoglous, 1992; Cout et al., 1994).

The anaerobic processes can be further classified according to the dry matter content and the feeding of the fermenting reactor. According to Tchobanoglous (1993) and his work team, we can talk about semidry procedures in the range of 15-20% dry matter contents. If the dry matter content is high, only batch reactors operated with the principle of filling and emptying can be applied, in order to avoid difficulties due to the continuous feeding.

On waste water treatment plants of small and medium capacity, the waste water sludge can not be economically stabilized by the conventional anaerobic treatment of low dry matter content and continuous feeding. Thus, the sludge is usually stabilized by composting in that cases. At waste water treatment plants of great capacity, the sludge is stabilized by anaerobic treatment of liquid, continuous technology which is often followed by composting, in order to achieve better material characteristics of the end product.

The municipal waste management directives require that the organic content of the wastes to be dumped should be reduced. The realization of the waste management goals requires the stabilization of municipal organic wastes, where generally composting is applied. The sewage sludge and the organic fraction of municipal solid waste, called vegetable, fruit and garden (VFG) waste are different from each other regarding their materials and quality, yet for their stabilization, combined treatment is more and more often applied. The quantity and quality of the VFG varies with time and space, depending on the season, the structure of the settlement and the standard of living.

The novel dry batch BIOCEL technology was introduced for the treatment of municipal solid organic waste in the Netherlands. It has the advantage that it is simple to operate, and

its specific reactor volume projected to the treated material flow is low (Brummeler et al., 1991; Brummeler, 2000; Simon, 2000). The investment costs of the dry batch BIOCEL technology are lower by 40% than those of the continuous anaerobic systems (Brummeler et al., 1992). Its advantage over composting by state-of-the-art technology comes from a simpler technical solution and a more economical operation.

We assume that the dry batch anaerobic treatment could be used for combined anaerobic treatment of VFG wastes and municipal sewage sludge. When treating the waste water sludge and other municipal organic wastes together by anaerobic method, the possible too high easily degradable organic content of the VFG might be a problem, because in lack of sufficient seeding material, it can lead to acidification of the system. A number of literature reports about the anaerobic treatment of different organic wastes separately (Brummeler, 1993), but there are no results available regarding co-digestion by dry anaerobic treatment.

The effective anaerobic conversion of organic substances into methane depends on the activity of miscellaneous microbial populations. A diagram of the consecutive metabolic stages, which can be distinguished in anaerobic digestion, is shown in figure 1. In well balanced digestion, all products of a previous metabolic stage are converted into the next one. The overall result is a nearly complete conversion of the biodegradable organic material in the waste into end products such as methane, carbon dioxide, hydrogen sulphide, ammonia, etc. without significant build-up of intermediate products.

The products of the fermentation vary depending on quality of raw material and environmental conditions applied. Low pH values decreases the relative amount of acetic acid and increases the relative amount of propionic acid (Breure & van Andel, 1984). Partial pressure of hydrogen in the gas phase can significantly influence the kind of products formed by fermentative bacteria (Wolin & Miller, 1982). Hanaki et al. (1981) stated that β -oxidation of long-chain fatty acids is thermodynamically unfavourable unless the hydrogen partial pressure is maintained at a very low level. The dependence of a low hydrogen partial pressure makes, that long chain fatty acids degradation can be inhibited indirectly by inhibition of hydrogen consuming organisms (Koster, 1989).

The high substrate affinity of the hydrogen-consuming micro organisms makes it possible to maintain low hydrogen concentrations. According to Robinson & Tiedje (1982), the Michaelis-Menten half-saturation constant (K_m) for hydrogen is in the range of 5.8-7.1 μ M. Zehnder et al. (1982) stated, that in a well balanced methane fermentation, the hydrogen partial pressure does not exceed 10^{-4} atm and in most cases approximately 10^{-6} atm.

Macro and micro nutrients contents of the treated raw material effects the yield of micro organisms. Lettinga et al. (1981) advised for macro nutrients a COD to nitrogen to phosphorus ratio in a range of 350 : 5 : 1 - 1000 : 5 : 1.

The precondition of the efficient application of the anaerobic batch reactors is the establishment of the balance between the acid production and the methane production, in the absence of the reactor getting acidified (Benedek, 1990). During the anaerobic degradation of the organic material, four consecutive metabolic steps can be distinguished: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Batstone et al., 2002).

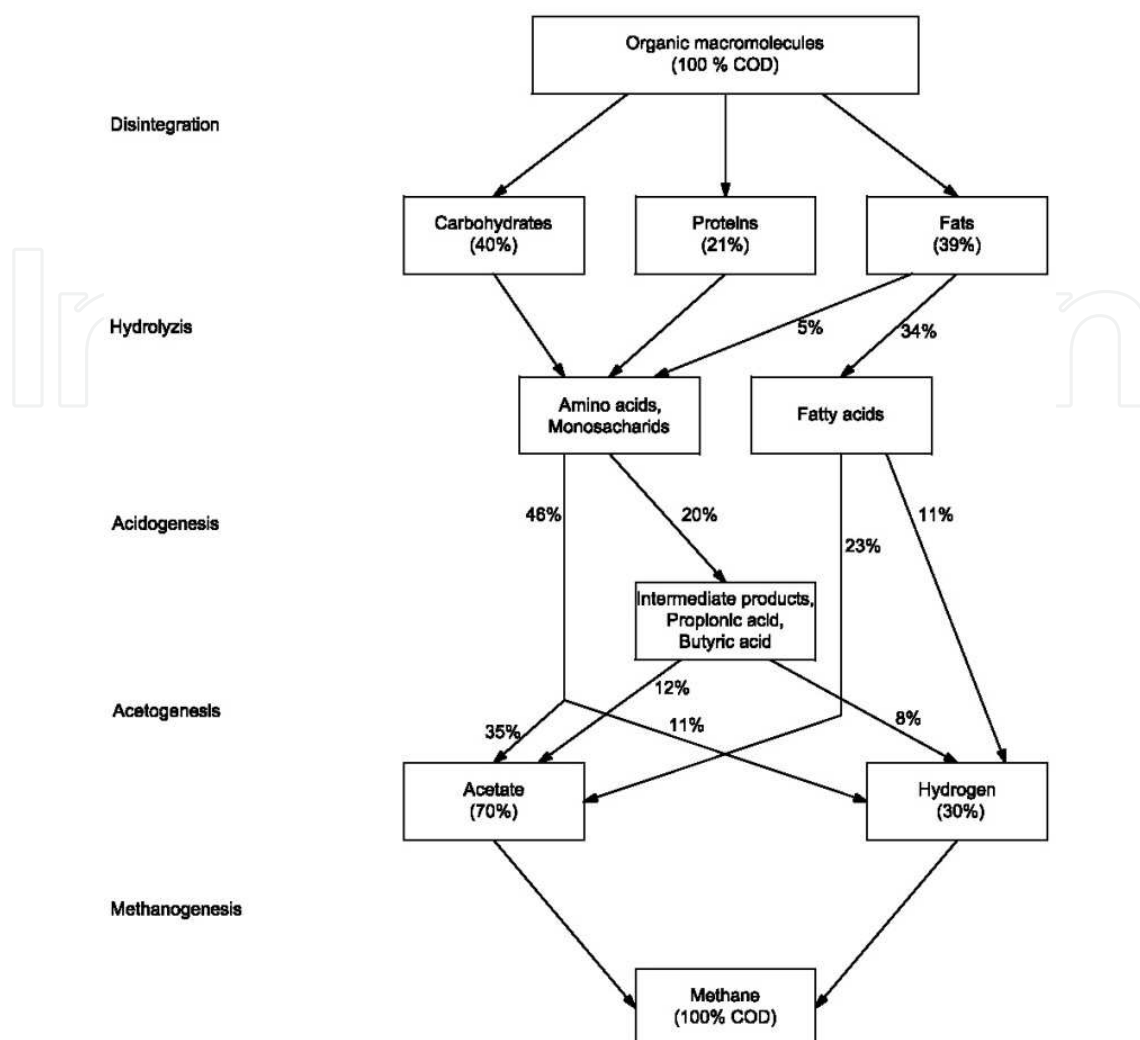


Fig. 1. Metabolic stages and products in anaerobic digestion of complex organic material

Among them, the usual rate-limiting factor of the whole procedure is the methanogenesis (Gosh & Klass, 1978). The rate of the acid production is great compared to that of the methane production. At a balanced anaerobic degradation process, the elimination rate of the biologically degradable organic dry material is almost equal to that of the methane production (Gujer & Zehnder, 1983), because the biomass production is negligible.

The research and the thermodynamic calculations show that 70% of the methane is generated during the decarboxylation of the acetic acid, and the remaining 30% comes from the reduction of the carbon dioxide (Jeris & McCarthy, 1965; Kaspar & Wuhrmann, 1978).



So, the efficiency of the methane production is characterized not only by measuring the methane content, but also by determining the hydrogen content. In case the hydrogen is accumulated and is not converted to methane, then the accumulated hydrogen will immediately inhibit the oxidation of the propionic acid and the accumulated acetic acid. This will result in decrease in pH and, thus, in acidification of the reactors. This again will

affect the oxidation of the hydrogen, decreasing the reaction efficiency and increasing the partial pressure of the hydrogen (Gujer & Zehnder, 1983).

To keep the degradation process balanced, seeding material is needed. A significant effect in balancing the process can be achieved by properly setting the ratio of the methanogen seeding material. However, the determination of the optimal amount of the seeding material is a complex issue which is of great importance to the operation of batch reactors being economical. Low seeding material ratio, in extreme cases, can lead to acidification of the reactor or, in better cases, moderates the process rate. This can be compensated by extending the retention time associated with increased reactor volume.

The increase of the biogas production and the decrease of the treatment time can be achieved also by increasing the quantity of the seeding material since this way a more effective degradation can be counted on. However, increasing the quantity of the seeding material can result in the increase of the reactor volume, too.

The optimal waste to seeding material ratio in the case of municipal solid organic wastes is 1:2.3 in laboratory, while less than 1 : 1 in full scale conditions (Brummeler, 1993). According to related literature data, the duration of the treatment in cases of municipal organic waste is around 30-36 days (Brummeler et al., 1991, 1992); however in cases of a low seeding material ratio, the duration of the treatment can be 50 days or more (Brummeler et al., 1992). There is no published data about seeding material demand for the dry, batch anaerobic co-treatment of the biowaste and waste water sludge.

We assume that the combined dry batch treatment of VFG waste generated on settlements and of sewage sludge has many advantages. As a result of the co-digestion, because of the different easily degradable organic contents of the sewage sludge and VFG, we can count on the increase of the gas yield projected to reactor volume, compared to a separate treatment of the VFG and sludge. We can assume as an advantage that a more balanced quality of the sewage sludge can have a positive effect on the co-digestion with organic wastes having quality varying with time and space. A further advantage can be, from the aspect as a potential of anaerobic treatment of the sewage sludges generated on smaller settlements, that the increased waste flow with VFG can make it economical. Nevertheless, it is necessary to investigate the appropriate seeding material ratio, the determination of which does not depend only on the achievable methane yield but on the required duration of the treatment and on the targeted stabilization goal of organic material, too.

Our aim is to study the combined dry batch treatment of VFG and sewage sludge. Our goal is to evaluate the aspects of determination of the optimal seeding material ratio, besides the study of the avoidance of acidification of the reactors, the achievable greater degradation rate of organic material and the maximal gas yield.

2. Materials and methods

In order to achieve our goals, we carried out laboratory experiments with dry batch reactors.

2.1 Materials

To ensure the repeatability of experiments, we modelled the biowaste (mixture of sewage sludge and VFG) generated in the settlements with a material mixture of fixed ratio as

follows: 50% municipal excess sludge, 50% VFG consisting 25% fresh grass and 25% kitchen waste. The excess sludge came from the activated sludge technology of a municipal waste water plant, which can be characterized with a 20-day sludge retention time. The kitchen waste consisted of 25% potato peel, 15% lettuce, 15% bread, 15% cucumber peel, 10% cabbage, 10% paper and 10% coffee grounds.

The amount of total solids (furthermore as TS), volatile solids (furthermore as VS) and the value of chemical oxygen demand (furthermore as COD) of the waste and the sludge are presented in Table 1.

Materials	Total solids (TS %)	Volatile solids (VS %)	Chemical oxygen demand (COD) (g O ₂ · kg TS ⁻¹)
methanogenic seed (digested sludge)	24.54	56.86	667
excess sludge	28.87	48.22	556
fresh grass	31.30	92.20	985
potato peel	18.51	94.33	1 074
lettuce	7.69	85.67	1 193
bread	65.35	97.36	1 094
cucumber peel	4.82	84.44	1 486
cabbage	8.79	90.98	1 086
paper	92.49	98.98	1 288
coffee grounds	34.30	99.28	1 145

Table 1. Characteristics of waste and sludge used for the experiment

To characterize the seed, we defined its stability and methanogenic activity. The seed was not stable, it could be degraded by a further 13%. The organic degradation occurred mostly within the first 30 days. The digested sludge came from a completely stirred tank reactor operated with 20 days hydraulic retention time. The methanogenic activity of the seed was 0.026 CH₄-COD · g VS⁻¹ · d⁻¹, which shows the maximum methane production measured in chemical oxygen demand (COD) of digested sludge for a unit of volatile solid in a unit of time.

2.2 Methods

The TS content and the volatile solids (VS) content of the samples were determined by drying and burning to constant weight at a temperature of 105°C and 650°C, respectively. The chemical oxygen demand (COD) of the sludges was measured by the standard method MSZ 21976-10:1982.

The amount of biogas generated, was measured by an „A1” type, Schlumberger wet gas meter. The methane and hydrogen content of biogas was measured by a Shimadzu 2014 gas chromatograph. The temperature of the column was 60°C, the temperature of the injector was 170°C, and the temperature of the detector was 250°C. As carrier gas we used nitrogen with 20 mL/min gas flow. In the 3.0-m long, 3.00-mm internal diameter glass column, Supelco Molecular sieve filling was put. The detection was done with TCD detector. We measured the quantity and the methane content of the biogas every day at the beginning, and then, when the amount of the biogas decreased, every other and then every fifth day.

To determine the methanogenic activity of the seeding material we used neutralized acetic acid as a substrate. To decrease the retardatory effects we added macro- and micro-nutrients (Biotechnion, 1996), and incubated the samples on the temperature of 35°C. We used liquid-phased mixed reactors to decrease the substrate-gradient. The amount of biogas generated, was calculated on the basis of pressure changes in the head-part of the 1.5 dm³ reactors. To remove the generated CO₂, NaOH pellets were placed in the heads-part of the reactors. Specific methanogenic activity of the seed was calculated on the basis of cumulative methane production graphs by taking the tangent of the deepest slope of the curve.

The acidity of the sludge was checked by a pH meter (340i WTW) pH/mV measuring device, to which a SenTix 41 type electrode was connected.

2.3 The experimental setup

We performed the examination of the effects of the seeding material on the dry batch anaerobic treatment by a series of reactors of a total capacity of 6 dm³, which consisted of 4 reactors, each of a capacity of 1.5 dm³, connected in parallel. By these set ups, the disturbing effects (opening of reactors) occurring during the pH measurements were reduced (Figure 2). The reactors were connected to gas-collecting bags.



Fig. 2. Set of dry batch anaerobic reactors

As experimental variable we checked five different seeding material ratios. We set the organic waste to seeding material ratios projected to the quantity of dry organic material, to these values: 1:0.5; 1:1; 1:1.5; 1:2, and 1:3. We measured the gas production of the seeding material (digested sludge) in a control reactor, thus, the degradation rate of the biowaste could be calculated separately. We compared the treatments when the sewage sludge is treated alone and when is co-digested with VFG waste, with the 1:1 seeding material ratio usually applied in the practice for the anaerobic treatment of municipal organic wastes. We kept the reactors in a room of a constant temperature of 34°C.

Each reactor was filled with an equal amount and quality (TS=22%) of waste. In order to prevent the disturbing effects caused by the oxygen, we flushed the heads of the reactors with nitrogen gas after the sampling. The diluting effect of the head-space was considered at the calculation of the results.

2.4 The quantification of anaerobic degradation

The COD of methane produced in the anaerobic degradation of organic substrate corresponds with the COD of the removed organic mass (Lettinga & Hulshoff Pol, 1990). The amount of organic matter removed during the anaerobic treatment, the degree of degradation, was determined by measuring the total amount of methane produced during the period (T), which was converted to COD, taking into account that 1 Ndm³ methane is equivalent to 2.86 g CH₄-COD. Based on this, the degree of degradation of the organic material was defined by the formula below:

$$D_T\% = (\sum \text{CH}_4 \text{ COD}_T / \text{sludge COD}) \times 100 \quad (1)$$

We fitted a logistic function-relation ($D_T\% = D_{\max} / (1 + e^{-k(t-t_0)})$) to the measuring results with SPSS 14.0 software. We used sludge as seeding material and the substrate for the tests after storing at 5°C, therefore we had to calculate with the lag phase in the beginning by choosing the logistic function-relation. The logistic curves take into consideration the start-up phase, pursuant to the Monod and the Briggs-Haldane model.

We determined the value of maximum degradation (D_{\max}) in case of biowaste and sludge for the fitting as 65% and 50% respectively, which values were based on our former own measuring results (Rózsané et al, 2011) and on technical literature data (Haug, 1980). We determined the k invariant of reaction speed and the t_0 time defining the inflexion point in a way that the function-relation would have the best fit (R^2) of the measuring results.

In the case of methane production projected to the volume of reactor, we did not deduce the methane production of the seeding material, but we used the results for the whole volume of the mixture of waste and seeding sludge. In case of the measuring results used for the volume of the reactor, we fitted the function-relation in a way identical with the previous, where the maximal degree of methane production ($\text{CH}_{4\max}$) was determined with the account of substrate to seeding material mixing rates and the maximal degradability. To characterize the speed of the degradation process, in the case of both measuring results, we determined the values of the starting v_{10d} and v_{30d} degradation speed as the direction tangent to the fitted curves.

3. Results and evaluation

We assumed that the balance of the multi-stage anaerobic digestion process can be influenced by setting the ratio of the seeding material which results in greater degradation of the organic content of the treated waste, as well as in greater methane production.

We evaluated the experimental results based on two aspects:

- based on the degradation of the organic material achievable with different seeding material ratios; and

- based on the gas production achievable during the treatment, referred to the unit of reactor volume.

3.1 The results of the organic matter degradation

The actual methane production of different mixtures of organic wastes and seed, referred to one unit of treated organic material, is shown in Figure 3. The methane production of the seeding material present in the reactor was deducted from the methane production of the mixture of the waste and seeding material. As a result, because of the relatively high degradability of the seeding material, in the case of unbalanced reactors caused by low seeding material ratios, we had even negative methane production in the first 20 days which was indicated as zero value.

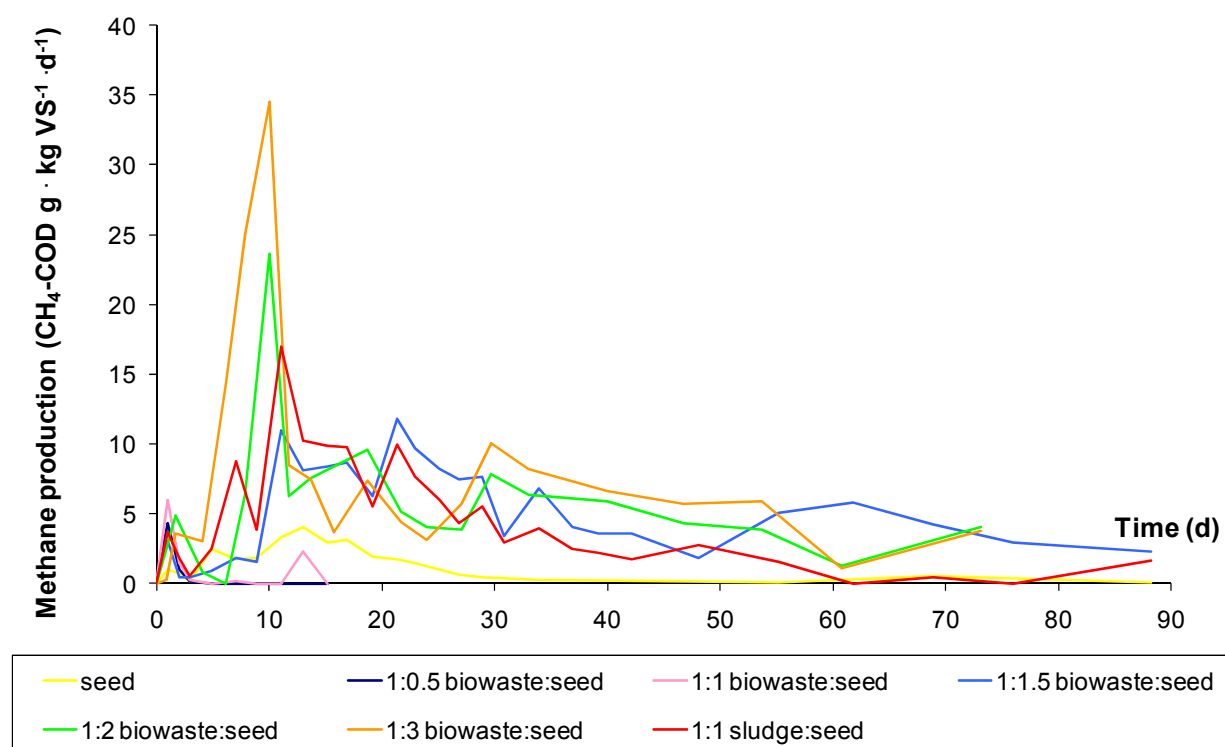


Fig. 3. Actual methane production referred to one unit of treated organic material

We reached the highest methane yield with the 1:3 biowaste to seed ratio. With the increase of the seed ratio, the methane production grew, too. The methane yield was very low in the case of 1:0.5 and 1:1 biowaste to seed ratios. Due to the low seed ratio, the waste became acidified (pH 5.5-5.8), so thus the process of methane production was also inhibited. Since our goal was to determine the optimal seeding ratio, we carried out the test in these reactors only for 15 days. The maximal methane production of the seeding material (digested sludge) occurred on day 10, however its extent was one eighth of that of the balanced reactors and the methane production decreased to zero after the 30 days.

Having compared the treatability of the sewage sludge and of the biowaste, with the 1:1 seed ratio applied in practice, we can state that in the case of the sewage sludge, a more balanced reactor performance can be observed. The results suggest that in the case of reactor

containing VFG as well, the easily degradable organic material content was higher than in the case of the reactor containing only sewage sludge. The fatty acid accumulated in the reactor containing VFG which led to the acidification of the reactor, in the end. Against the acidification of the biowaste, in the case of the sludge, the values of pH and hydrogen concentration were better than the critical level even in the initial critical phase of the treatment. This calls the attention to that, because of the varying quality of VFG waste, the determination of the seeding material ratio has to be estimated case by case in each practical application.

We can calculate the degradation of organic material of the waste from the quotient of the methane production totalled in the time and of the chemical oxygen demand of the waste mixture. Figure 4 shows the rate of degradation against time for different seeding rates and substrates (the methane production of the seeding material is deducted). Onto the measurement results we fitted the logistic function describing biological processes ($D_t\% = D_{max} / (1 + e^{-k(t-t_0)})$). The reaction kinetic parameters are shown in Table 2. The value of k reaction rate constant rose with the increase of the seeding material ratio which resulted in decrease of the value of t_0 . Significant differences cannot be detected in the values of k and t_0 of the 1:1.5 and 1:2 mixing ratios.

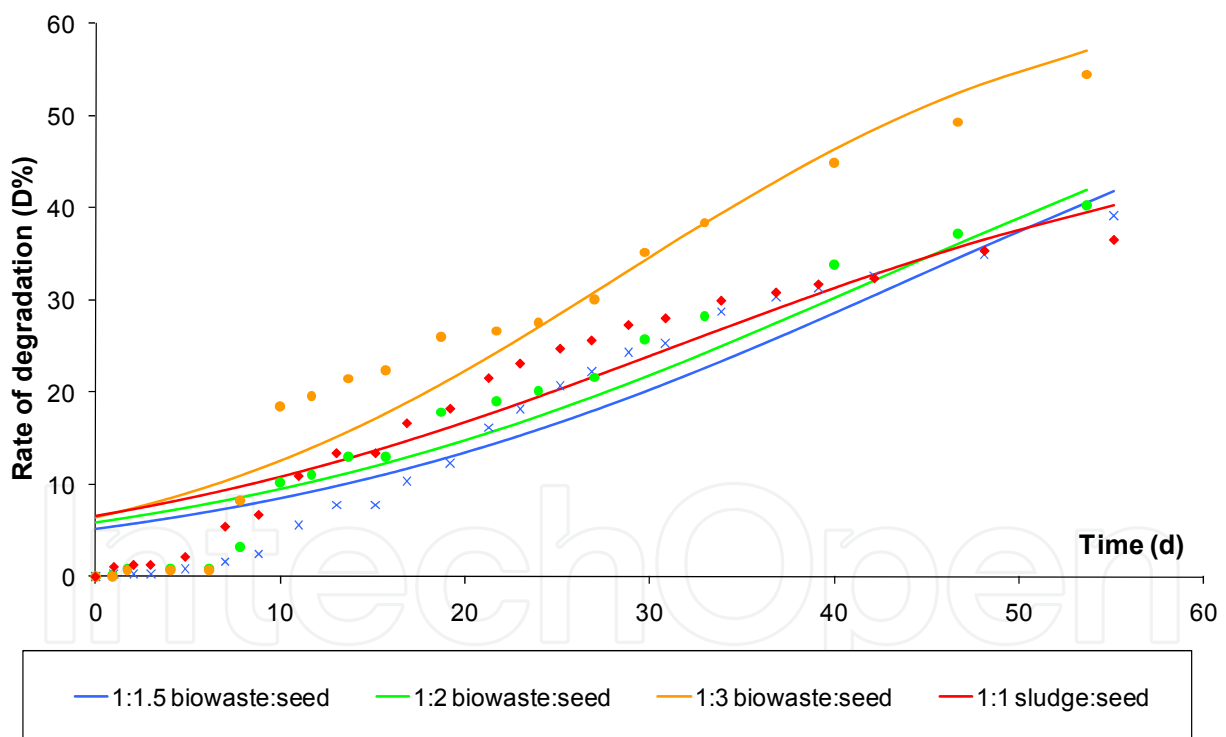


Fig. 4. The degradation rate of organic wastes against time

According to our measurement results, with a 60-days treatment with 1:3 biowaste to seed ratio, 54% organic material degradation can be achieved. In the case of biowaste to seed mixtures of 1:1.5 and 1:2 ratios, only 41-43% of the organic material became decomposed during the same period of time. Thus, when increasing the amount of seeding material with improving the initial conditions of the treatment, a considerable impact in the degradation rate of organic material can be achieved for the whole treatment period.

The description of the sample	k ($1 \cdot d^{-1}$)	t_0 (d)	R ²	V _{10d} (D% · d ⁻¹)	V _{30d} (D% · d ⁻¹)
1:1.5 biowaste:seed	0.055	44.33	0.936	0.424	0.788
1:2 biowaste:seed	0.054	42.58	0.918	0.453	0.782
1:3 biowaste:seed	0.078	28.29	0.939	0.820	1.256
1:1 sludge:seed	0.060	31.38	0.876	0.526	0.749

Table 2. Kinetic parameters of the degradation process

Considering the rates of actual methane production, we can see that the actual rates measured on day 10 significantly increase with the growth of the amount of seeding material. At the values related to day 30, the effect of seed ratio onto the methane production can be still well detected. The actual rate of the methane production further increased from day 30 also in each cases, which suggests that we can count on a considerable degree of degradation even after day 30. This is confirmed by the t_0 value, as well.

To characterize the process of the anaerobic degradation, we checked the hydrogen content of the biogas, as well as the temporal evolution of the pH of the reactors in the most critical initial phase of the treatment (Table 3). The hydrogen content of the biogas was above the value of the detection limit only in the first 9 days.

Type of the reactor	2nd day		3rd day		5th day		7th day		9th day	
	H ₂ (%)	pH	H ₂ (%)	pH	H ₂ (%)	pH	H ₂ (%)	pH	H ₂ (%)	pH
1:0.5 biowaste:seed	9.66	5.47	0.38	5.51	1.08	5.55	0.08	5.65	0.06	5.70
1:1 biowaste:seed	4.27	5.70	0.19	5.80	0.13	5.75	0.02	5.78	0.02	5.83
1:1.5 biowaste:seed	3.58	5.90	0.14	5.84	0.10	6.13	0.02	6.06	0.01	6.34
1:2 biowaste:seed	1.40	6.27	0.04	6.32	0.02	6.34	0.01	6.43	0.01	6.59
1:3 biowaste:seed	0.37	6.10	0.05	6.23	<dl	6.45	0.01	6.65	0.01	6.72
1:1 sludge:seed	0.62	6.68	<dl	6.94	<dl	7.09	<dl	7.28	<dl	7.37

Table 3. The hydrogen content of biogas and the pH of wastes in the case of different wastes and seeding ratios

It is seen in the case of biowaste that, by the increase of seeding ratio, the hydrogen content of the biogas decreases and the pH of the waste in reactors increased. During the test period, the hydrogen content of the biogas also decreases and then, following day 9, it is under the value of detection limit. The critical hydrogen concentration, above the 0.01 % as calculated based on the literature (Zehnder et al., 1982), measured in the first 5 days had a negative effect on the methane production in the case of each seeding ratio (Figure 3). By the increase of the seeding, above the ratio of 1:1.5, the hydrogen concentration decreased below the critical value from day 9 and the methane production started to increase. The unfavourable values of hydrogen and pH measured in the case of 1:0.5 and 1:1 ratios led to the acidification of the reactors. The pH of the reactors increased during the test which resulted in the rise of biogas production. During the anaerobic treatment of the sewage sludge, we did not measure significant hydrogen quantity in the biogas even in the case of 1:1 sludge to seed mixing ratio. This can be explained by that there is less easily degradable organic material in the sewage sludge than in the tested biowaste which is responsible for the

accumulation of hydrogen and volatile fatty acids. At sewage sludge digestion, often the hydrolysis appears as the process limiting step (Koster, 1989) which could contribute to the more favourable values measured in the case of sludge.

We compared our measurement results with the operation data of a full scale BIOCEL plant (Brummeler, 1993) (Table 4.). The literature refers the biogas quantities to wet waste mass, to standard condition. For comparability we recalculated the literature data to the CH₄-COD g · kg VS⁻¹ unit used by us.

Time (d)	Cumulative methane production (CH ₄ -COD g · kg VS ⁻¹)			Degradation of the organic material (D%)		
	Full scale BIOCEL plant ¹	Laboratory scale		Full scale BIOCEL plant ²	Laboratory scale	
		1:3 seed to biowaste ²	1:1 seed to sludge		1:3 seed to biowaste ²	1:1 seed to sludge
5	110.0	22.9	18.4	7.7	1.2	1.6
10	297.7	157.2	98.1	20.9	13.4	8.4
20	660.0	278.7	173.9	46.3	23.7	14.9
40	-	453.5	286.5	-	38.6	24.6
60	-	551.6	325.9	-	47.0	28.0

¹Value calculated according to Brummeler (1993), 450 m³ reactor, waste TS 36%, VS 65%

²Methane production together with the methane production of the seeding material

Table 4. Comparison of the laboratory results with the operation data of a full scale BIOCEL plant treating VFG

The results of Table 4 show that the results of the methane production referring to VFG waste reviewed in the literature, at the same moment, significantly exceed the results of the co-digestion of the biowaste with sewage sludge. In our experiment, the difference resulting from the lag phase as well as the lower degradability of the biowaste containing sludge and VFG can be definitely pointed. In our experiment half of the waste mixture was sewage sludge. The sewage sludge applied by us was less degradable than the biowaste, thus, the degradability of one unit of waste mixture (and so the amount of methane production from it, too) was lower.

The results of Table 4 show that higher gas yield referred to one unit of organic matter can be reached in the case of co-digestion of VFG and sewage sludge than in the case of sewage sludge digestion alone.

3.2 The results of methane production referred to reactor volume

We assume that the seed ratio, as a result of two opposing effects, influences the methane production per reactor volume unit. The increase of the seed ratio makes the anaerobic process balanced but at the same time decreases the amount of degradable organic matter per reactor volume unit. That is a question, to what extent the already digested material should be recycled for seeding. Another question is how the co-digestion of the easily degradable VFG and sewage sludge affects the gas production of the reactors. To answer the question, we checked the values of the totalled methane production referred to reactor

volume unit for the sewage sludge and biowaste (consisting of 50% sludge and 50% VFG) at seed ratios shown in Figure 5.

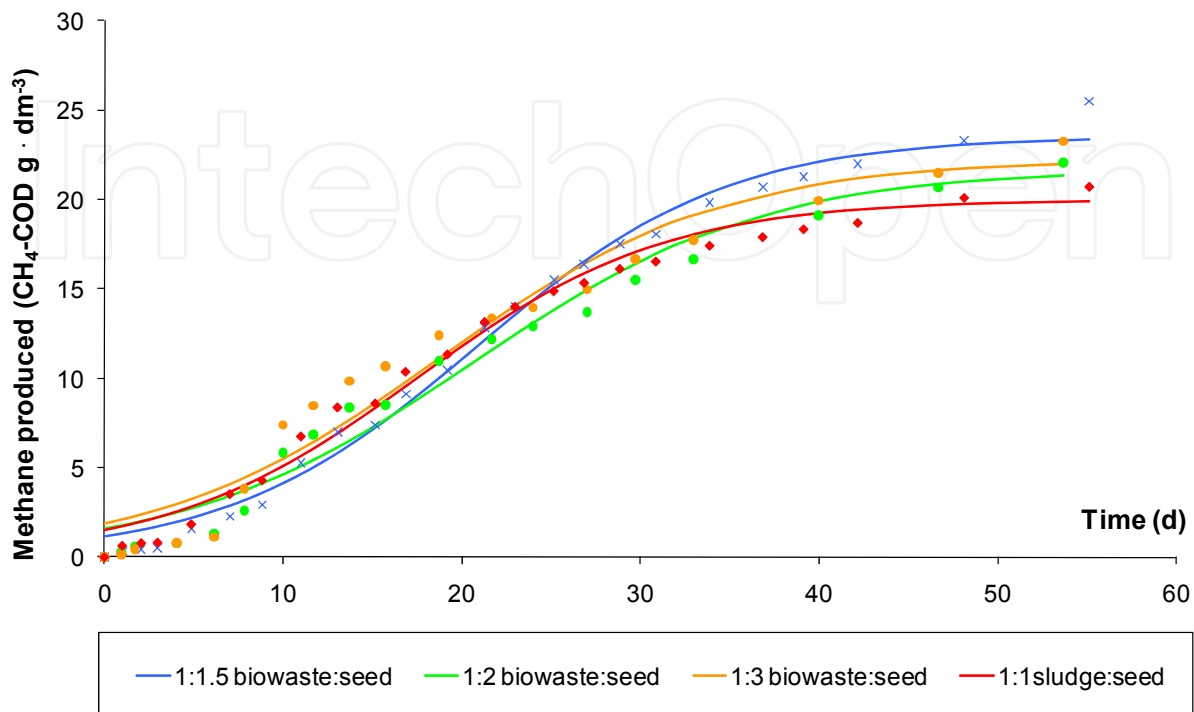


Fig. 5. Summarized, specific methane production on the basis of reactor volume against time

Figure 5 shows that in the case of methane production referred to reactor volume, the methane production of the sewage sludge above 30-day retention time is lower than that of the combined treatments, so thus, we can achieve higher gas yield from one unit of reactor volume when the sewage sludge and the biowastes are treated together than in case the sewage sludge is applied alone. We achieved maximal methane production with co-digestion at the 1:1.5 waste to seed ratio, this is followed by the 1:3 and 1:2 waste to seed ratios, however, significant difference between the measurement results cannot be detected. The increase of the seed ratio, in spite of the more inert material filling up the reactor volume, did not considerably reduce the methane production projected to reactor volume unit until day 30 of the treatment. A great increase of the amount of the seeding material, however, results in increase of the reactor volume necessary to the actual treatment capacity which, at the same time, is associated with the same rate of increase in gas production. Taking into consideration also the goal of stabilization, based on the comparison of Figures 4 and 5, we can state that it may be worth to count on the reduction of the retention time while increasing the seed ratio, for the purpose of optimization of the gas yield, degradation and volume demand.

The reaction kinetic parameters of results referred to the reactor volume are shown in Table 5. It is apparent from the results of the table that the values of the maximal methane production are nearly the same, no significant differences can be detected. The value of k reaction rate constant is the highest in the case of 1:1.5 biowaste to seed ratio and its value equals to the k value relating to the sewage sludge.

Type of the reactor	CH ₄ produced (CH ₄ -COD g · dm ⁻³)	v _{10d} (CH ₄ -COD g · dm ⁻³ · d ⁻¹)	v _{30d} (CH ₄ -COD g · dm ⁻³ · d ⁻¹)	k (1 · d ⁻¹)	t ₀ (d)
1:1.5 biowaste:seed	23.56	0.529	0.503	0.143	20.85
1:2 biowaste:seed	21.68	0.505	0.485	0.123	20.59
1:3 biowaste:seed	22.26	0.586	0.442	0.127	18.75
1:1 sludge:seed	19.97	0.578	0.305	0.144	17.49

Table 5. Kinetic parameters of summarized methane production appertaining to the volume of the reactor

In the case of the values of actual methane production relating to day 10, we did not gain in each case higher v₁₀ value when increasing the seeding ratio. The v₃₀ value relating to day 30 is in all cases less than the v₁₀ value which indicates the decrease of methane production. In the case of v₃₀ values, we experienced that, when increasing the seeding, the value of actual methane production referred to reactor volume unit and relating to day 30 decreased.

We assume that the treatment period (retention time) affects the gas production of the reactor. The question is, taking into account the enhancement of gas production in the reactor and at the same time the degradation rate indicating the efficiency of the treatment, what retention time the reactors ought to be designed to. Figure 6 shows the average methane production determined for the treatment period (specific methane production referred to time and volume unit) depending on the duration of the treatment.

Figure 6 clearly shows the differences between the sewage sludge and the biowaste containing VFG, too. At the biowaste, as a result of the higher proportion of the easily degradable organic material due to the VFG, with the reduction of the retention time from 30 to 10 days, the gas yield grew in the case of 1:2 and 1:3 seeding ratios. At the 1:1.5 seeding ratio, because of the initial unfavourable conditions (pH, hydrogen), this effect occurred later between day 20 and 40. Because of the sludge being less degradable, the methane production gradually increased until day 40.

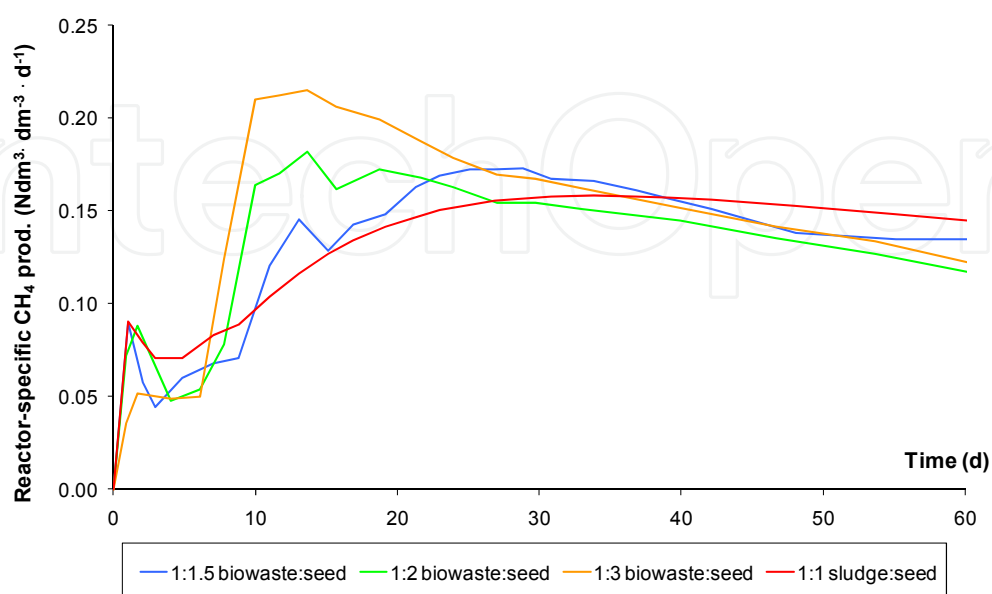


Fig. 6. Average methane production in the case of different biowaste : seed ratios

Figure 6 shows that in each case of waste to seed mixture, the average methane production reaches its maximum after day 10 and then after day 30 it starts to decline. This means that the retention time has to be minimum 30 days in the case of a combined dry batch treatment of VFG waste and sewage sludge. In the case of higher seeding ratios, following 30-40 days, the average methane production is almost the same in the case of each seeding, so thus, the effect of the seeding prevails less. Figure 6 confirms, that optimizing the anaerobic treatment, it is worth to check, together with the increase of the seed ratio, the option of reducing the retention time. It can be stated that the application of the seeding in 1:3 ratio has no negative impact on the gas production of the reactors even above a 40-day retention time assuring high grade stabilization.

4. Conclusion

Based on the test results we stated that the sewage sludge can be well degraded also through co-digestion by dry batch treatment together with VFG waste. We stated that in the case of 1:0.5 and 1:1 biowaste to seed ratios, the reactors became acidified. Even in the case of higher seeding ratios 9-day initial „lag” phase can occur. The hydrogen content of the biogas and the pH in the reactors indicate an initial accumulation of fatty acids in the reactor. We measured the highest, 54% organic material degradation in the case of 1:3 biowaste to seed ratio. Comparing our measurement results with literature data, it can be stated that the total methane production projected to one unit of organic material and the organic material degradation is nearly the same in total. Our laboratory-scale experiment, however, was influenced by the relatively long „lag” phase. Based on our tests it can be stated that it is a complex task to determine the optimal seeding ratio and retention time where a universal value cannot be given. In practice, the optimal values have to be determined one by one, taking into consideration the degradation target together with the specific gas yield projected to the reactor. From the aspects of costs reduction regarding the investment and operation, based on the values of the gas productions referred to the reactor volume, the 1:1.5 biowaste to seed ratio seemed to be the most efficient. This lets the conclusion be drawn that it is not worth to recycle the seeding material in the reactors in a higher ratio than this. According to the above, the compromising waste to seed ratio taking into consideration the different aspects is minimum 1:1.5 which takes into account the higher degradation of the organic material, as well as the quantity of the methane producible from one unit of reactor volume and the demand for low investment costs.

In the case of the same seed ratio, we experienced great difference in the efficacy of the treatment in case of biowaste containing VFG and the sewage sludge. During a co-digestion of sewage sludge and VFG wastes, because of the VFG waste having a quality varying in space and time, it is advisable to determine the suitable seed ratio through degradation tests in advance.

5. Acknowledgment

This research was funded by the Scientific Fund of the Eötvös József College.

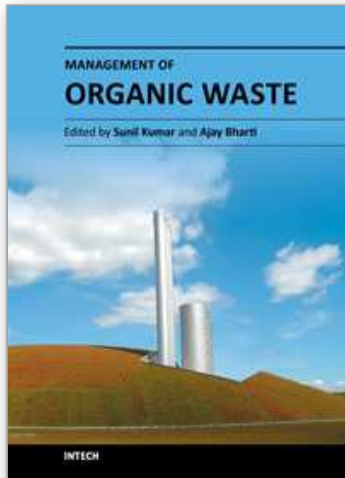
6. References

Batstone, D. J., Keller, J., Angelidaki, R. I., Kalyuzhnyi, S. V., Pavlostathis, S. G., Rozzi, A., Sanders, W. T. M., Siegrist H., & Vavilin V. A. (2002). *Anaerobic Digestion Model No.*

- 1 (ADM1) *Scientific and Technical Report No. 13 IWA Task Group for Mathematical Modelling of Anaerobic Wastewater* IWA Publishing, London, England, pp. 88.
- Benedek, P., Major, V., Réczey, G., & Takács I. (1990). *Biotechnológia a környezetvédelemben*, Műszaki Könyvkiadó, ISBN 963-10-8224-5, Budapest, Hungary
- Biotechnion (1996): *Laboratory methods and procedures for anaerobic wastewater treatment*, Wageningen Agricultural University, Department of Environmental Biotechnology, The Netherlands
- Breure A. M., & van Andel J. G. (1984). *Hydrolysis and acidogenic fermentation of a protein, gelatine, in an anaerobic continuous culture*, Applied Microbiology Biotechnology 20. pp. 40-45
- Brummeler ten, E., Horbach H. C. J. M., & Koster I. W. (1991). *Dry anaerobic batch digestion of the organic fraction of municipal solid-waste*, Journal of Chemical Technology and Biotechnology, Volume: 50 Issue: 2, pp. 191-209.
- Brummelet ten, E., Aarnink M. M. J., & Koster I. W. (1992). *Dry anaerobic-digestion of solid organic waste in a BIOCEL reaktor at pilot-plant scale*, Water Science and Technology, Volume: 25 Issue: 7, pp. 301-310.
- Brummeler ten, E. (1993). *Dry Anaerobic Digestion of the Organic Fraction of Municipal Solid Waste*, Doctoral Thesis, Wageningen Agricultural University, Wageningen, The Netherlands.
- Brummeler ten, E. (2000). *Full scale experience with the BIOCEL process*. Water Science and Technology: Vol. 41 (3) pp. 299-304.
- Cout, D., Gennon, G., Ranzini, M., & Romano, P. (1994). Anaerobic co-digestion of municipal sludges and industrial organic wastes. In: *Proceedings of the 7th International Symposium on Anaerobic Digestion*. Johannesburg, South Africa.
- Ghosh, S., & Klass, D. L. (1978). *Two-phase anaerobic digestion*. Process Biochemistry 13(4) pp. 15-24.
- Gujer, W., & Zehnder A. J. B. (1983). *Conversion processes in anaerobic digestion*. Water Science and Technology 15. pp. 127-167
- Hanaki, K., Matsuo T., & Nagase M. (1981). *Mechanism of inhibition caused by long-chain fatty acids in anaerobic digestion process*, Biotechnology Bioengineering, 23. pp. 1591-1610
- Haug, R. T. (1980). *The Compost Engineering. Principles and Practice*, Ann Arbor Science Publishers, ISBN 0-250-40347-1, Michigan, The USA
- Jeris, J. S., & McCarty, P. L. (1965). *The Biochemistry of Methane Fermentation Using ¹⁴C tracers*, Journal WPCF 37, No. 2 . pp. 178-192.
- Kaspar, H. F., & Wuhrmann, K. (1978). *Kinetic parameters and relative turnover of some important catabolic reactions in degesting sludge*. Appl. Environ. Microbiol.
- Kayhanian, M., & Tchobanoglous, G. (1992). Pilot investigation of an innovative two-stage anaerobic digestion and aerobic composting process for the recovery of energy from the organic fraction of MSW. In: *Proceedings of the 5th International Symposium on Anaerobic Digestion*. Venice, Italy.
- Koster, I. W. (1989). *Toxicity in anaerobic digestion with emphasis on the effect of ammonia, sulfide and long-chain fatty acids on methanogenesis*, Doctoral dissertation, Wageningen Agricultural University, Wageningen, The Netherlands
- Lettinga, G. & Hulshoff Pol, L. W. (1990). Basic aspects of anaerobic wastewater treatment technology. In: *Anaerobic reactor technology, International Course on Anaerobic Waste Water Treatment*, Wageningen Agricultural University

- Lettinga, G., Zeeuw, W. J., & Ouborg, E. (1981). *Anaerobic treatment of wastes containing methanol and higher alcohols*, *WaterRes.*, 15. pp. 171-182
- Robinson, J. A., & Tiedje, J. M. (1982). *Kinetics of hydrogen consumption by rumen fluid, anaerobic digester sludge and sediment*, *Applied Environmental Microbiology*, 44. pp. 1374-1384
- Rózsáné, Sz. B., Simon, M., & Füleky, Gy. (2011). Effect of anaerobic pretreatment by dry batch technology on aerobic degradability of sewage sludge, In: *Anaerobic Digestion: Processes, Products and Applications*, Nova Science Publishers, ISBN 978-1-61324-420-3. In press
- Simon, M. (2000). *Települési szerves hulladékok kezelése és hasznosítása*, PhD értekezés. Debreceni Egyetem, Agrártudományi Centrum, Mezőgazdaságtudományi Kar, Környezetmérnöki Intézet, Víz- és Környezetgazdálkodási Tanszék, Debrecen
- Tchobanoglous, G., Theisen, H., & Vigil, S. (1993). *Integrated Solid Waste Management*. Chapter 9, McGraw-Hill, New York.
- Wolin M. J., & Miller, T. L. (1982). *Interspecies hydrogen transfer: 15 years later*, *ASM News*, 48. pp. 561-565
- Zehnder A. J. B., Ingvorsen, K. & Mari, T. (1982). Microbiology of methane bacteria, In: Hughes, D. E. et al. (eds.) *Anaerobic Digestion 1981*, Elsevier Biomedical Press, Amsterdam, The Netherlands, pp. 45-68
- MSZ 21976/10:1982 Települési szilárd hulladékok vizsgálta, Kémiaileg oxidálható szervesanyag-tartalom meghatározása

IntechOpen



Management of Organic Waste

Edited by Dr. Sunil Kumar

ISBN 978-953-307-925-7

Hard cover, 198 pages

Publisher InTech

Published online 01, February, 2012

Published in print edition February, 2012

This book reports research on the utilization of organic waste through composting and vermicomposting, biogas production, recovery of waste materials, and the chemistry involved in the processing of organic waste under various processing aspects. A few chapters on collection systems and disposal of wastes have also been included.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Beatrix Rózsáné Szűcs, Miklós Simon and György Füleky (2012). Co-Digestion of Organic Waste and Sewage Sludge by Dry Batch Anaerobic Treatment, Management of Organic Waste, Dr. Sunil Kumar (Ed.), ISBN: 978-953-307-925-7, InTech, Available from: <http://www.intechopen.com/books/management-of-organic-waste/biogas-production-by-dry-batch-anaerobic-co-digestion-of-organic-waste-and-sewage-sludge->

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

IntechOpen

IntechOpen