Anaerobic Fermentation of Food Waste: Comparison of two Bioreactor Systems

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The scope of the following work was to compare two possibilities of using organic waste materials from food industry for producing biogas, which can be further converted to heat and electricity. To efficiently convert food waste to biogas, it is necessary to choose the most appropriate process, reactor system and parameters. Therefore, fermentation experiments in two reactor types - CSTR (Continuous Stirred Tank Reactor) and FBR (Fluidized Bed Reactor) were examined.
The fermentations revealed yields of 670 NL biogas/kg VS (CSTR) or 550 NL biogas/kg VS (FBR) and productivities of 3.9 NL biogas/(L*d) for CSTR and 3.4 NL biogas/(L*d) for FBR system. The average methane concentration was about 60 % CH_4 for each of both reactor type fermentations. The achieved results showed that it was possible to produce biogas by using both of the tested reactor systems. However, the FBR experiments indicated advantages concerning the process stability.

1. Introduction

The primary aim of this project is an efficient utilization of waste from food industry, which can be realized by anaerobic fermentation. These organic residues are mixtures of different kinds of waste tending to cause process failures due to their strongly varying composition. Depending on the main component of the produced biogas the anaerobic process can be designed as a single stage fermentation to achieve mainly methane or as two stage fermentation to obtain hydrogen and methane.
In this study the single step fermentation was investigated comparing two different types of bioreactor systems: On the one hand the biogas production was performed in a conventional Continuous Stirred Tank Reactor (CSTR), which served as a reference for the second system, and on the other hand, the fermentation was carried out in a Fluidized Bed Reactor (FBR) with internal circulation.
Systems like the FBR are characterized by a higher stability of the process as well as higher biogas yields and productivities, due to retaining biomass (Nishio et al., 2007). Besides the mentioned advantages of the FBR, this system is expected to stand significantly higher organic loads compared to the CSTR.
As already stated in literature, food waste turns out to have considerable potentials for its efficient utilization to energy. Related to the composition of the residues and the kind of experiments, several deliverables have been reported. El-Mashad et al. (2010) found

methane yields of approximately 350 L/kg VS in single-stage batch tests. Also higher ranges of up to 440 L CH_4/kg VS were documented (Zhang et al. (2007)). Moreover, laboratory scale experiments with yields about 350 L methane/kg VS as well as 640 l methane/kg VS achieved in pilot scale were determined by Beck et al., whereas Grasmug and Braun (2002) reported yields of 1100 L biogas/kg VS with methane contents of 72 %. Concerning the mentioned literature results the varying concentration of organic substances has to be implicated.

2. Methods

2.1 Substrate

The substrate used for the fermentations was derived from the biogas plant of Zellinger GmbH in Upper Austria and consisted of fruits and vegetables, vegetable and animal feedstuff, leftovers, waste from industrial kitchen, biological residues, manure, content of fat separator, waste from dairies as well as blood. The fermentation temperature was set to 40 °C for all fermentations.

The mean chemical composition of the used material is summarized in Table 1. The analysis indicated quite a low pH value, which can be due to the previous hygienisation that is required for this kind of substrate and might lead to loss of biogas production because of the already started process of acidification.

Table 1: Characteristics of the feedstock

Parameter	Unit	Average value
NH_4	g/kg	1.88
CSB	g/kg	135.92
N_{total}	g/kg	5.43
pH		4.18
Total solids (TS)	% wet basis	11.44
Volatile solids (VS)	% dry basis	89.29
Volatile solids (VS)	% wet basis	10.20
Lactic acid	mg/L	21 622
Acetic acid	mg/L	8 848
Propionic acid	mg/L	1 336
Butyric acid	mg/L	2 537

2.2 Experimental set-up

In both reactor types the experiments were conducted in continuous mode with increasing organic loads. Compared to the fermentation with CSTR the organic load of the FBR system was increased in bigger steps and shorter periods, which had a considerable influence on the performance of the bioreactor system as it is shown in the results. The operating volume of the bioreactors amount 3 l in CSTR and 6 l in FBR, schemes of both reactors are displayed in Figure 1.

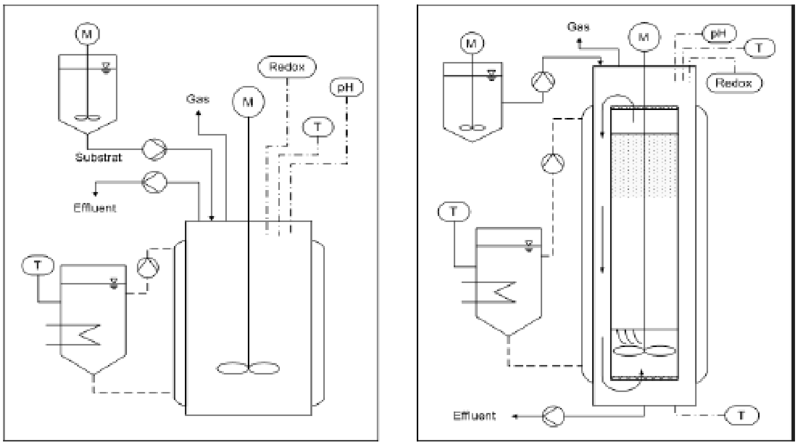

Figure 1: Scheme of CSTR system (left) and FBR system (right)

3. Results and Discussion

3.1 CSTR

The organic load in the CSTR fermentation was increased slowly, with minor changes. Therefore, the microorganisms had the chance to adapt to each loading stage, which resulted in rather high loads, yields and productivities achieved, as can be seen in *Table 2*. The highest yield (894 NL biogas/kg VS) was obtained at an organic load of 7.3 g VS/(L*d), whereby simultaneous remarkable fluctuations from 520 - 900 NL/kg volatile solids (VS) could be observed. These varying values were most probably devoted to numerous influences: substrate change and partial overload (between 2.3 and 5 g/(L*d)) leading to lower yields. This fact caused periods with moderately increased organic loadings (5 – 7.3 g/(L*d)) and resulted in high yields, leaving sufficient time for adaption. The CSTR fermentation run exhibited a maximal productivity of 8.3 NL biogas/(L*d) at 16.4 g/(L*d).

Table 2: Load, methane yield and productivity of CSTR bioreactor

Organic load [g VS/L*d]	Methane yield [NL CH_4/kg VS]	Methane productivity [NL CH_4/L*d]
0.6	431	0.3
1.2	336	0.4
1.7	509	0.9
2.3	437	1.0
3.5	315	1.1
4.9	302	1.5
5.3	408	2.2
6.0	483	2.9
6.7	500	3.3
7.3	503	3.7
9.1	377	3.4
12.8	315	4.0
16.4	284	4.7
20.1	431	0.3

Although the CSTR bioreactor was accelerated quite slowly, fluctuations in the developing of productivity and yield were observed, shown in
Figure ***2***. Nevertheless, mean yield and productivity of about 670 NL/kg VS and 3.9 NL/(L*d) were reached.

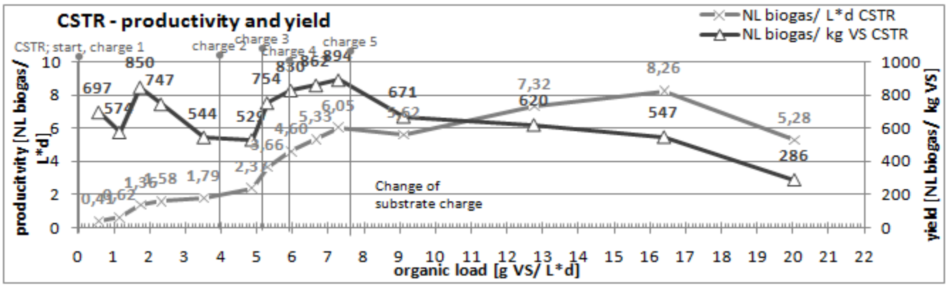

Figure 2: Results CSTR – biogas productivity and yield at each organic load

3.2 FBR

Concerning the fermentation in the FBR system it has to be stated, that start and enhancing the organic load were conducted faster, which might cause the variation at low loads, compare to Table 3.

Table 3: Load, methane yield and productivity of FBR bioreactor

Organic load [g VS/L*d]	Methane yield [NL CH_4/kg VS]	Methane productivity [NL CH_4/L*d]
0.5	208	0.1
1.1	211	0.2
1.6	248	0.4
2.7	287	0.8
3.8	332	1.3
5.2	405	2.1
6.6	391	2.6
8.2	440	3.6
10.1	403	4.1
12.4	321	4.0
14.6	233	3.4

Thus there were noticed some ups and downs in the beginning, averaged productivity of 3.4 NL biogas/(L*d) and yield of 550 NL biogas/kg VS have been obtained. Biogas yields of the FBR fermentation were steadily increasing (350 – 700 NL/kg VS) with increasing organic load. These increasing figures could be attributed to slowly developing biofilm. The maximal yield found was 709 NL biogas/kg VS.
The maximal productivity found for the FBR fermentation was 6.5 NL biogas/(L*d) at a organic load of 12.4 g VS/(L*d).

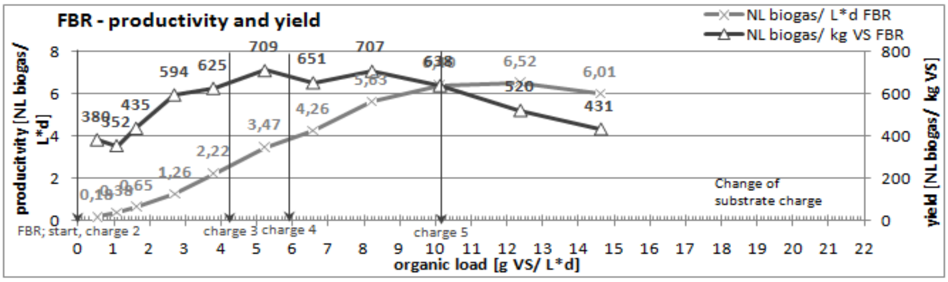

Figure 3: Results FBR – biogas productivity and yield at each organic load

3.3 Comparison CSTR – FBR

Comparing the biogas yields at increasing organic loads, for the fermentation in the CSTR system higher levels were obtained to an extent of about 26 %. However, simultaneously higher fluctuations were found in this system, showing the increased sensitivity of a CST bioreactor in contrast to the FBR, where biomass is retained in the system.

Biogas productivity did rise with increasing organic load in general. Above a certain level the productivity declined due to overload. A 28 % higher value was obtained for fermentations in the CSTR system, but only at a 32 % increased organic load.

Furthermore it is remarkable that the optima for biogas yields and productivities were not found at the same level of organic load. The maximal yield was generally obtained at lower organic loads in contrast to the maximal productivity.

The fact that the CSTR system exhibited apparent better performance data than the FBR system in the course of this work has different reasons: System based reason: Stirring might have caused slower or limited biofilm formation in the FBR due to shear forces. The fluidisation could be realized by pumping. On the other hand, intermittent stirring of the CSTR enhanced formation of microbial flocs, providing sufficient time to create a kind of biomass retention on solid particles present in the substrate. A process based reason is the utilisation of different substrate charges at different levels of organic load, which should be taken into account for direct comparison, as well as the different periods of operating time (CSTR: 8 months, FBR: 6 months running period).

Figure 4 and

Figure 5 visualize the results as explained above.

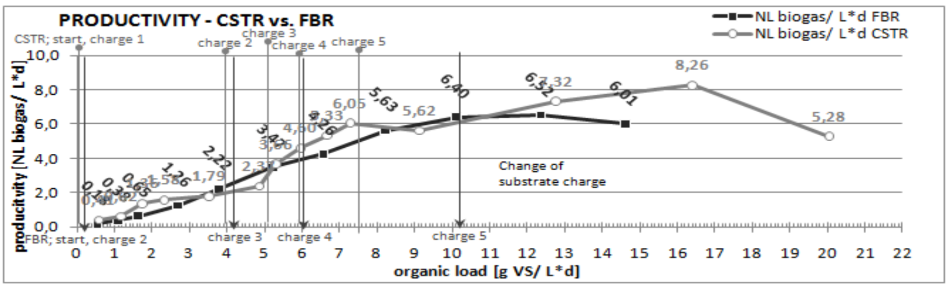

Figure 4: Comparison CSTR and FBR – biogas productivity

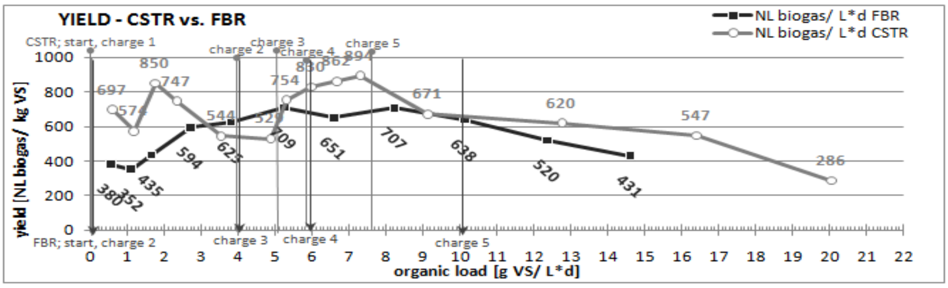

Figure 5: Comparison CSTR and FBR – biogas yield

4. Conclusion

Efficient biogas production from food waste using different bioreactor systems was successfully demonstrated. Compared to literature results, the yields and productivities achieved in this work are absolutely appreciable. Highly stable operation at high organic loads in the FBR system was proven and considerable good performance at elevated, but limited organic loads by using a CST reactor was found.

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