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Co-digestion of food waste in a municipal wastewater treatment plant: Comparison of batch tests and full-scale experiences

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ABSTRACT

The effects of co-digestion of food waste in a municipal wastewater treatment plant (WWTP) were studied in batch tests. The results obtained were compared with the mass balance of a digester at a full-scale WWTP for a one-year period without and with the addition of co-substrate. The specific methane yield calculated from the balance was 18% higher than the one in the batch tests, suggesting a stimulation of methane generation by co-digestion. It was hypothesized that this increase was caused by shifting the C/N ratio of raw sludge (8.8) to a more favourable ratio of the added food waste (17.7). In addition, potential benefits by adding food waste for energy autarky was investigated. While just 25% of the total energy demand of the plant could be recovered by biogas generation when no co-substrate was fed, this percentage has more than doubled when food waste was added at a ratio of 10% (w/w).

1. Introduction

About one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons per year (Gustavsson et al., 2011). The total amount of food waste generated within the EU-27 in 2010 was estimated at 89 million tons per year, i.e. 179 kg/(capita * year), where households (43%) and manufacturing (39%) produced the largest fractions (Segré and Gaiani, 2012). In Germany, about 4.4 million tons (54 kg/(capita * year)) were separately collected as organic waste in the households and another 3.6 million tons originated from food processing facilities, resulting in a total amount of 8.0 million tons of food waste generated in 2012 (www.destatis.de, 2014).

On the other hand, the amount of sewage sludge to be treated is decreasing in Germany for many years. Between 1998 and 2010, the accrued amount of sewage sludge decreased by more than 14% or 308,000 tons of total solids, respectively (Wiechmann et al., 2013). Assuming an average moisture content of 3.5% (Wiechmann et al., 2013), the available treatment capacities in the sludge digesters of wastewater treatment plants (WWTP) in Germany totals to about 8.8 million tons, which compares well with the amount of food waste produced. A similar trend of decreasing sewage sludge production is also observed in other European countries as well as in North America (Dominguez and Gujer, 2006). Performing co-digestion is considered as one great opportunity to recover the potential of food waste as a renewable energy source in the future (Iacovidou et al., 2012; Murto et al., 2004).

A simple and effective tool to assess the effect of adding co-substrates to a digester is a batch test (Angelidaki et al., 2009; Koch and Drewes, 2014; Strömberg et al., 2015). However, due to their limited duration and mode of operation, batch tests are less suitable to provide information regarding possible positive or negative synergistic effects due to mixing of different substrates (VDI 4630, 2006). Nevertheless, Koch et al. (2015b) reported that although batch tests are limited in assessing synergistic effects on methane yield, they are suitable to evaluate changes on degradation kinetics and the formation of methane. Using batch tests, Labatut et al. (2011) observed changes in the specific methane yield (SMY) in co-digestion of several substrates in relation to the weighted average of the individual substrates' SMY and reported both synergistic and antagonistic effects. Nielfa et al. (2015) reported similar observations in batch tests mimicking co-digestion of the organic fraction of municipal solid waste and biological sludge.

According to Koch et al. (2015b), co-digestion of raw sludge with food waste is recommended up to a ratio of 12% (w/w) or 35% (based on volatile solids, VS), respectively. Co-digestion can result not only in a higher methane yield (which is just caused by the higher methane yield of food waste compared to raw sewage sludge), but also in an accelerated methane production. This finding corresponds very well with results revealed by Kim et al. (2003), who observed the highest methane production rate

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in co-digestion of sewage sludge with food waste in the range of 30–40% VS under mesophilic conditions.

Reports on full-scale sludge co-digestion practices are scarce in the peer-reviewed literature and mainly focusing on technical requirements and economic efficiency (Björnsson et al., 2000; Dereli et al., 2010; Krupp et al., 2005; Lübken et al., 2007; Park et al., 2011). Mata-Alvarez et al. (2014) assume that this is likely due to the low interest of the industrial sector to publish their results in the scientific literature. However, they also show that the interest in co-digestion is rapidly growing given the number of papers published. Their comprehensive literature review revealed only studies from full-scale wastewater treatment plants performing co-digestion with the organic fraction of municipal solid waste (OFMSW), fruit and vegetable waste (FVW) as well as used cooking oil, while no studies were found focusing on co-digestion of food waste (Mata-Alvarez et al., 2014). This might be attributed to the fact that the term food waste is not very clear defined, hampering the comparability of different studies (Alibardi and Cossu, 2015).

This paper is filling the lack of experiences reported from full-scale digester facilities treating food waste as co-substrate. Since it is not possible to study all aspects of co-digestion, this study focusses on the effects on methane yield by comparing results from batch tests with practices in the field. Therefore, the results obtained in batch tests are compared to the performance of a full-scale wastewater treatment plant performing co-digestion in the optimal ratio of approximately 10% (w/w) by balancing the digester over one period with and one without the addition of co-substrate. Both systems were fed with the same kind of food waste. A special focus of the study was also on the impact of co-digestion on energy self-generation and the amount of co-substrate necessary to become energy self-sufficient.

2. Materials and methods

2.1. Source and characteristics of inoculum and substrates for batch tests

For the batch tests, inoculum and thickened raw sludge (RS) samples were collected from the wastewater treatment plant (WWTP) Garching/Munich (20 km north of Munich, Germany), treating mainly municipal wastewater of approximately 30,000 population equivalents. RS was comprised of a mixture of primary and secondary sludge dominated by municipal waste activated sludge. RS at this facility was treated under mesophilic conditions (approximately 40 °C) with a hydraulic retention time of about 25 days. Effluent of the digester was used as inoculum.

Food waste (FW) was provided by the company Berndt GmbH (Oberding, Germany). Food leftovers from canteens as well as expired food products were processed in a unit separating interfering substances and subsequently sanitized by thermal treatment at 120 °C and 2 bar for at least 20 min. This procedure is extensive, but compulsory by the European Commission Regulation (EU 142/2011) in order to be able to market the product. Lipids were separated for biodiesel production. The final product after this treatment was characterized as an energy-rich pulp-like substrate, which was assumed to be fast and easily degradable due to this pre-treatment.

The determination of totals solids (TS) and volatile solids (VS) followed German Standard Methods for the examination of water, wastewater and sludge (DEV, 2015). The stability criterion TVFA/alkalinity (so called FOS/TAC) is the quotient of the content of volatile fatty acids (TVFA) and the buffer capacity measured as total inorganic carbon (alkalinity). TVFA and alkalinity were determined by titration according to Kafle and Kim (2011). Average characteristics of inoculum and substrates are summarized in Table 1.

2.2. Batch tests

The batch tests were conducted with the Automatic Methane Potential Test System II (Bioprocess Control Sweden AB), which was specially designed for the determination of biochemical methane potential (BMP). The system consists of 15 glass bottles each of 500 ml with a working volume of 400 mL. The samples were stirred in cycles of 5 min mixing and 25 min resting. The biogas produced passed through a CO_2 capturing unit, is measured through liquid displacement and the force of buoyancy and was automatically converted to standard temperature and pressure (0 °C and 1 bar). A more detailed description of the system can be found in Strömberg et al. (2014). The data were recorded by a data acquisition system and automatically transferred to a MS Excel™ file for analysis and visualization.

The batch experiments were repeated four-times under the same conditions using the same mass-based mixing ratios (5%–30% in steps of 2.5%). Trials were repeated using a fresh charge of inoculum, raw sludge and food waste contributing to the changing compositions of the substrates. As 15 individual experimental set-ups were available, each trial consisted of one bottle with just inoculum (to account for the gas production from the inoculum only), two bottles of RS, one bottle of FW, and twelve bottles with a mass-based mixture of FW to RS of 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, 20%, 22.5%, 25%, 27.5%, and 30%, respectively. The ratio of inoculum to substrate was chosen to be 2:1 on a volatile solids (VS) basis (VDI 4630, 2006). Prior to incubation, the bottles were flushed with nitrogen gas at a flow rate of 10 L/min for 30 s (Koch et al., 2015a). All tests were carried out under mesophilic conditions (38 ± 1 °C) until the daily gas production was less than 1% of the total gas production (according to VDI 4630 (2006)).

Table 1
Average characteristics of inoculum, thickened raw sludge, and food waste in the batch tests as well as WWTP Garching/Alz (only total solids and volatile solids concentrations were available).

	Batch test			WWTP Garching/Alz	
	Inoculum	Raw sludge	Food waste	Raw sludge	Food waste
Total solids (%)	2.35 ± 0.09	5.43 ± 0.13	18.2 ± 1.02	3.69 ± 0.20	17.5 ± 2.32
Volatile solids (% TS)	61.3 ± 1.17	79.5 ± 0.45	89.7 ± 1.93	72.7 ± 0.38	88.4 ± 1.56
pH value (–)	7.64 ± 0.10	6.33 ± 0.24	5.06 ± 0.20		
ΣVFA (g/kg)	1.49 ± 0.42	2.21 ± 1.21	2.11 ± 0.24		
TVFA/alkalinity (–)	0.35 ± 0.06	2.12 ± 1.21	n. a.		
COD (g/kg)	22.7 ± 1.34	72.0 ± 2.96	223 ± 5.71		
TOC (g/kg)	8.25 ± 1.23	25.2 ± 2.16	80.0 ± 4.36		
TKN (g/kg)	2.65 ± 0.21	2.87 ± 1.98	4.51 ± 1.05		
C/N ratio[a] (–)	3.1	8.8	17.7		

n. a. – not applicable due to too low pH value.
[a] Calculated value.