CO - DIGESTION OF MUNICIPAL BIOWASTE AND SEWAGE SLUDGE FOR BIOGAS PRODUCTION

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Abstact: The aim of the research project was to carry out the co-digestion of organic fraction of solid municipal waste in the form of source separated kitchen waste and sewage sludge. The influence of the kitchen waste as a co-substrate on the stability and efficiency of the process was determined. Mesophilic fermentation (36˚C) was conducted for sewage sludge as well as mixtures of sewage sludge and biowaste based on TS proportions. Moreover, the susceptibility of the digested samples to dewatering was assessed. The kitchen waste turned out to be highly desirable as co-substrate for methane fermentation. It exhibited a positive influence on the total biogas production, process stability, organic matter reduction (VS) as well as biogas yield. The sample with a TS proportion of 60% from kitchen biowaste turned out to be optimal. The capillary suction time (CST) measurement showed that co-digestion did not change significantly dewatering properties of the fermentation digestate.

Keywords: biodegradable waste, biogas, co-digestion, methane fermentation, renewable energy, sewage sludge.

INTRODUCTION

Poland produces about 10 million tonnes of solid municipal waste – ⅔ of the amount is produced by households and the rest by institutions Their chemical and morphological composition varies widely. It depends on the type of housing arrangement; heating system used; general standards of living and ecological awareness of the residents etc [GUS, 2008; Rosik-Dulewska, 2007].

One of the main ingredients of solid municipal waste is easily-biodegradable organic fraction (OFMSW), which consists of plant/animal kitchen waste; green waste; paper and cardboard etc. The amount of biodegradable waste produced in Poland in the base year of 1995 was estimated to reach 4,38 million tonnes, from which more than 95% was landfilled. The situation has not improved significantly since than. In 2004, the amount of biodegradable municipal waste increased by about 26 % in relation to the base year of 1995 and amounted to 5,52 million tonnes. What is more, about 4 millon tonnes of biodegradable waste are estimated to have been deposited, which is 91% of the amount deposited in the base year of 1995.

In accordance with the European Council Directive on the landfill of waste [European Council Directive, 1999], the member states are obliged to reduce gradually the amount of biodegradable waste deposited at municipal dump sites. A promising solution of the municipal biowaste utilization may be their co-fermentation with sewage sludge. Co-digestion technologies developed on the basis of digestion installations which had been in operation for decades before. The facilities have been mainly used to treat sewage sludge or manure. The main advantages of the co-digestion process are [Jędrczak, 2007; Braun, 2002]:

- increased biogas production;
- additional amount of fertilizer (soil conditioner);

- additional income (gate fees for waste treatment);
- higher organic matter bioconversion.

The literature contains a number of reports on successful digestion of biowaste,- both from selective collection as well as extracted from mixed municipal solid waste - treated with primary and/or excess activated sludge [Krupp et al., 2005; Sosnowski et al., 2003; Zupančič et al., 2008; Grasmug et al., 2003]; livestock wastes [Callaghan et al., 2001; Hartmann and Ahring, 2005]; as well as industrial organic waste, predominantly from food industry [Kapela et al., 2008; Fernández et al., 2005].

The main aim of the research project was to conduct the combined digestion of sewage sludge and biowaste as well as evaluate the effects of biowaste addition as a co-substrate on the overall stability and efficiency of the process as well as dewatering properties of the digestion residue. Such a solution will allow to develop a municipal waste utilization technology enabling the production of bioenergy and wastes utilization. It should also be noticed that investment and operation costs are lower in case of facilities meant to process a few types of waste.

MATERIALS AND METHODS

Thickened sludge taken from a full scale municipal treatment plant operated on the activated sludge method and organic fraction of the municipal solid waste (OFMSW) in the form of source-separated kitchen biowaste were used as digestion feedstock. The biowaste was collected selectively from households as well as institutions (restaurants, school canteens etc.) located in the vicinity of the wastewater treatment plant. A domestic food blender was used to homogenize the various components of biowaste into particles smaller than 2 mm in diameter. Than, it was stored in a refrigerator at 15˚C. Fermentation digestate from previous series of experiments was used as an inoculum for the following digestion trials. Table 1 presents the characteristics of the substrates used.

Table 1. Characteristics of the digestion feedstock.

Parameters	**Biowaste**	**Sewage sludge**	**Inoculum**
pH [-]	4,65	6,44	7,76
TS [%]	23,44	5,20	3,09
VS [%]	21,64	3,57	1,73
VS/TS	0,92	0,69	0,56
C_{org} [% TS]	55,18	38,44	31,02
N_{tot} [% TS]	2,94	4,98	3,28
Ammonia nitrogen [mg $N\text{-}NH_3/dm^3$]	-	18,3	1 850
COD [mg O_2/ dm^3]	-	292	1 620

Digestion unit and procedure

The digestion was carried out in a set of fermenters with a working volume of 3 dm^3. They were equipped with mechanical mixing devices controlled by an electric timer. Digesters were maintained at a constant temperature of 36˚C (±0,5) for 30 days. Their contents were mixed periodically – 5 minutes in every 3 hours. Figure 2 depicts digestion unit used for methane fermentation.

Figure 1. Digestion unit.

The process was carried out for sewage sludge exclusively (A – blank sample) as well as mixtures of kitchen biowaste and sewage sludge - based on total solids (TS) ratio: B (20:80); C (40:60); D(50:50); E (60:40); F (70:30). The prepared samples were mixed with inoculum at the weight ratio of 1:2. Table 2 presents the characteristics of the digestion trials.

Table 2. Characteristics of the digestion trials

Parameter	A	B	C	D	E	F
pH [-]	7,25	7,21	7,19	7,16	6,89	6,81
TS [% w/w]	3,77	4,22	4,67	4,88	5,33	5,83
VS [% w/w]	2,36	2,76	3,23	3,48	3,93	4,43
VS/TS [-]	0,62	0,65	0,69	0,71	0,74	0,76
C:N ratio	7,7	8,9	10,3	10,9	11,7	12,6

Dewatering measurement

The susceptibility of the digested samples was also determined. It was based on capillarity suction time (CST). The wetting time was measured as long as filtration layer covered the area between the circles of 32 and 45 mm.

Scope of the analyses

The scope of the analyses conducted before and/or after the digestion process encompassed: pH value measurement; total solids (TS), volatile solids (VS), total carbon (C) as well as total Kjeldahl nitrogen (TKN) determinations. The assays were also analysed for ammonium-nitrogen ($N\text{-}NH_3$), total volatile fatty acids (VFA), alkalinity as well as SCOD. In this case, analyses were conducted in the liquid phase after it had been centrifuged (13 000 rpm/min). In case of SCOD and $N\text{-}NH_3$, samples were additionally filtered through a 0,45 μm filter [Eaton 1995; Sawyer et al., 2003]. Both quantitative and qualitative analyses of the biogas produced were carried out during the experiment. The biogas was stored in a tube containing 5% NaOH solution. The recorded amounts of biogas were adjusted to the volume at standard temperature (0˚C) and pressure (1 atm). Biogas samples from each digester was stored and periodically analysed for CH_4 content (% vol.) [Zhang, 2007].

RESULTS AND DISCUSSION

Anaerobic digestion for methane production is a multi-step biochemical process, whereby macromolecular substances (fats, proteins, carbohydrates and their derivatives) are converted into simpler compounds. One of the most common parameters to measure the bioconversion is the degree of volatile matter (VS) reduction. Compared to the sample containing exclusively sewage sludge (42,8%), a higher degree of VS reduction was achieved in samples containing both sewage sludge and biowaste (between 45,7% and 63,6%), – Table 3. The highest value, i.e. 63,6% was recorded for the sample containing 60% of total solids from biowaste. Taking into account the achieved degrees of VS reduction, it allows to conclude that the co-digestion positively impacts the efficiency of bioconversion [Krupp et al., 2005; Dohanyos et al., 2004; Jędrczak, 2007], mainly by improving the C/N ratio, which is not optimal in case of sewage sludge. In our case, the C/N ratio of the analysed sludge amounted to 7,7. The optimal value of the ratio reported in the literature varies widely. It is frequently mentioned to fluctuate between 10 and 25 [Jędrczak, 2007]. The addition of biowaste as a co-substrate allowed to increase the C/N ratio to the level of 8,9-12,6 (Table 2). An increase in the proportion of biowaste was accompanied by a gradual rise in ammonia nitrogen – measured in the liquid phase. In this type of waste, ammonia comes mainly from degradation of protein and is considered a major factor affecting the process stability. A wide range of inhibiting ammonia concentrations has been reported in the literature – the value amounted to between 1,7 and 14g $N\text{-}NH_3/dm^3$ [Chen et al., 2008].

Table 3. Characteristics of digestion output.

Parameter	A	B	C	D	E	F
pH [-]	7,90	7,93	7,95	7,94	7,98	7,41
$TS_{reduction}$ [%]	31,3	33,6	35,4	37,7	45,2	43,9
$VS_{reduction}$ [%]	42,8	45,7	48,3	53,1	63,6	61,7
VFA/alkalinity [-]	0,11	0,09	0,16	0,05	0,09	0,69
Ammonia nitrogen [mg $N\text{-}NH_3/dm^3$]	1160	1250	1460	1590	1790	2060

However, the literature mentions several critical levels of ammonia concentration [Jędrczak, 2007] –Table 4. In this study, the recorded concentration of ammonia amounted to between 1160 and 2060 mg $N\text{-}NH_3/dm^3$. Comparing the results obtained with the levels presented in the table below, it is worth noticing that the results are in the inhibition range.

Table 4. The influence of ammonia concentration on the methane fermentation [Jędrczak, 2007].

Ammonia nitrogen concentration [mg /dm^3]	**Effects**
50÷200	stimulation
200÷1000	neutral
1500÷3000	inhibition
>3000	toxic

Another important stability indicator is VFA/alkalinity ratio [Dymaczewski and Sozański, 1995; Callaghan et al., 2002; Magrel, 2004]. A value of the ratio above 0,4 is believed to inhibit methanogens activity. In our study, only sample F, i.e. a mixture containing the largest kitchen biowaste proportion exhibited a VFA/alkalinity ratio above this value. In comparison to the samples containing exclusively sewage sludge (A), the remaining co-digested samples did not exhibit a significant increase in VFA/alkalinity ratio – Table 3.

As the assays were undergoing digestion, daily biogas production was recorded. Figure 2 shows daily biogas production recorded during the experiment. Compared to the blank sample (A), co-digested assays exhibited a significant increase in biogas production. The highest biogas production, i.e. 13,11 dm^3 was recorded for sample E containing 60% of TS from biowaste, which is almost four times more than in case of the sample containing exclusively sewage sludge. (3,61dm^3).

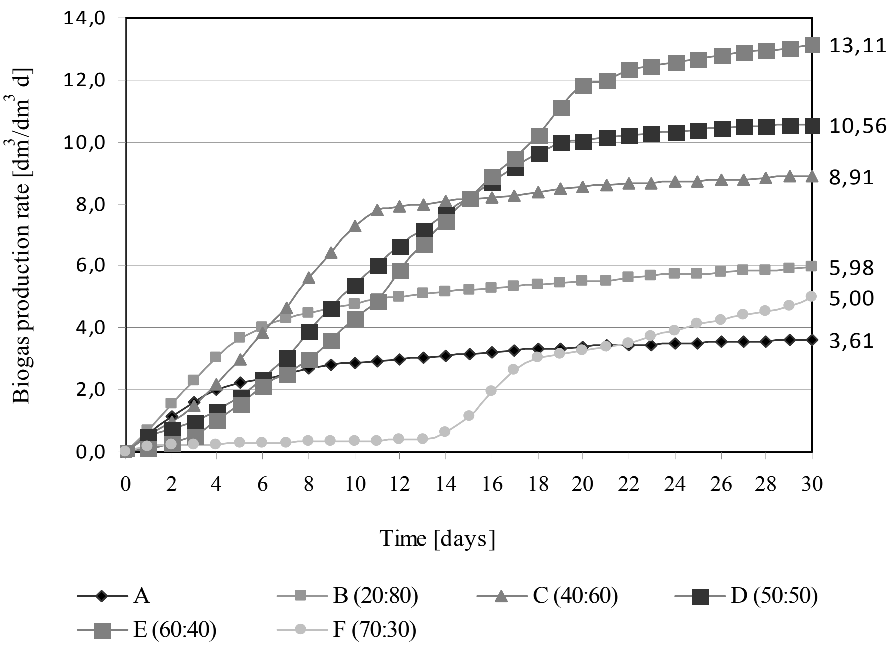

Figure 2. Biogas production rate.

A larger proportion of biowaste (sample F) caused a strong inhibition in methanogens activity, which significantly influenced the biogas production. However, a similar VS reduction was achieved in this case, if compared to the previous assay. Moreover, CH_4 content in the biogas produced was determined. It was established that samples containing exclusively sewage sludge contained 66% of methane. By contrast, the amount of methane in the co-digested samples fluctuated between 67 and 72%. The increase in CH_4 concentration might have been caused by the addition of ingredients containing large amounts of easily-biodegradable substances such as fats and proteins [Buraczewski,1989; Hartmann, 1996].

In order to assess the efficiency of the process, biomethanation results were recalculated and expressed in terms of biogas yields ($m^3/kg\ VS_{degraded}$) - Figure 3. Just as in case of total biogas production- except for the sample in which the fermentation process collapsed (F) – biogas yields rose in proportion to increase in total solids from biowaste. The highest index value, i.e. 0,527 $m^3/kg\ VS_{removed}$ was achieved for sample E containing 60% of TS from biowaste, which is about 46% more than more than in case of the blank sample - 0,361 $m^3/kg\ VS_{removed}$.

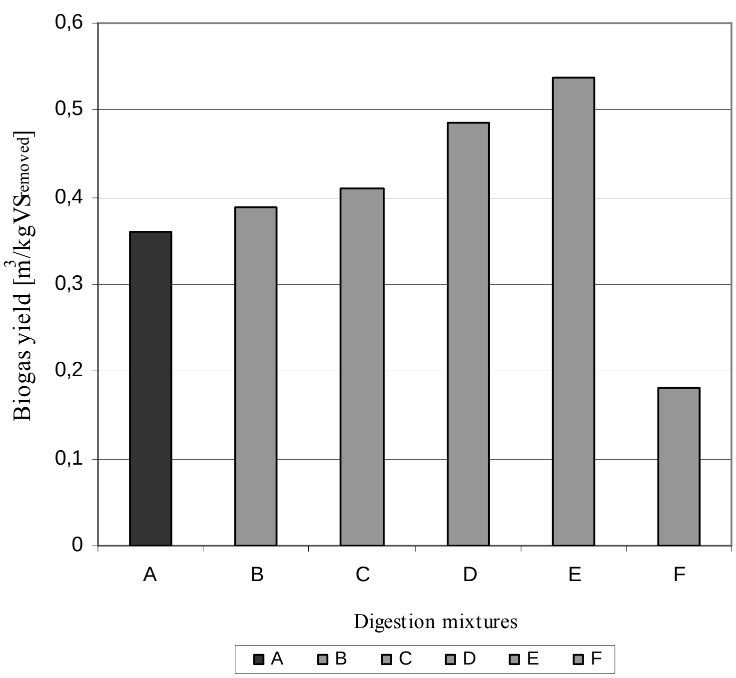

Figure 3. Biogas yields.

Capillary suction time (CST) measurement was applied for the assessment of the dewatering properties of the fermentation digestate. The results obtained are presented in figure 4. The value recorded for the blank sample (A) amounted to 420 s. The CST value of co-digested samples fluctuated between 425 and 469s as long as the content of TS from kitchen biowaste did not exceed the level of 60%. Above this level, the CST value increased sharply and amounted to 589 s.

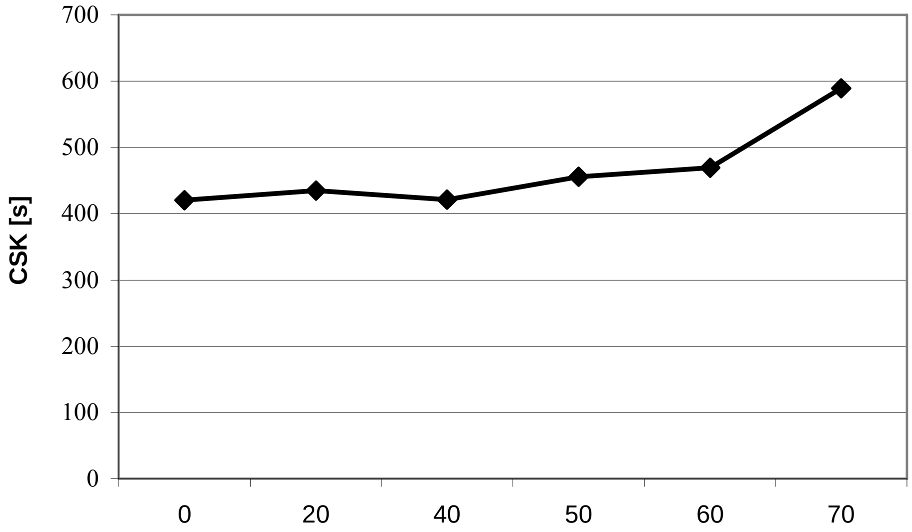

Figure 4. Capillary suction time (CST).

CONCLUSIONS

Taking into account environmental protection requirements as well as biowaste composition, the co-digestion of municipal biowaste from selective collection seems to be a promising option for their utilization. The research project allows to draw the following conclusions:

1. Co-digestion had a positive impact on the quantity and quantity (CH_4 content) of biogas produced (except for the sample in which the methanogenesis process was inhibited by VFAs accumulation and subsequent pH value decrease).
2. Compared to the sample containing exclusively sewage sludge (42,8%), a higher degree of VS reduction was achieved in samples containing both sewage sludge and kitchen biowaste (between 45,7% and 61,7%).
3. The addition of a co-substrate in the form of source separated kitchen waste influenced the biogas yields in a positive way.
4. Co-digestion did not cause a significant deterioration of dewatering properties of the digestate.
5. The optimal proportion of TS from a co-substrate (kitchen waste) amounted to 60%, which is tantamount to 25% if expressed as wet weight proportion. Under those conditions, the total biogas production increased almost four times and the process exhibited the greatest biogas yields.

The results achieved during the research project will be verified under continuous conditions. Additionally, an attempt will be made to increase the biogas production coming from the sewage sludge.

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