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Food waste – the source of biogas production increase in the municipal WWTPs

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Abstract
The contribution presents the possibility to use food and restaurant wastes for increasing of the biogas production in the Slovak municipal WWTPs. In 45 Slovak WWTPs (from the 520 total) the process of anaerobic fermentation with the biogas production is operated. The total volume of fermentation tanks is about 162 000 m^3 but the total daily biogas production is only app. 51 500 m^3/day. The contribution describes the several-month laboratory research of the utilisation of food wastes as the organic source of biogas production. The results have confirmed the high potential of the biogas production from food wastes – in average about 930 L of biogas to 1 kg VS. The influence of rejected sludge water from food wastes to biological process of treatment was also evaluated.

Keywords
Anaerobic digestion; biogas; food waste; municipal wastewater treatment plant; nitrogen removal

INTRODUCTION

The biogas production in the Slovak Republic is dominant mostly in municipal WWTPs. As it is known from (Bodík *et al. 2009*), the total designed capacity of 45 examined Slovak WWTPs is more than 6.5 Mil PE, with real load ca 2.6 Mil. PE. Many WWTPs have specific volumes of digestion tanks extremely high (higher than 80 – 100 L/PE). Average retention time of sludge in digestion tanks in Slovakia (together with storage tank) is about 33 days and is ranging between 12 to 92 days. In 2007 in Slovak WWTPs about 51 500 m^3 of biogas were produced daily that represent an average value ca 20 L/PE.day of specific biogas production (litre of biogas/PE.day). All presented data indicate that most of WWTPs have over-dimensioned or insufficiently loaded digesters and have free capacities for treatment of external substrates to biogas production.

Only 18 from 45 executed WWTPs have installed the equipment for electrical power production (combined heat and power, CHP) with total installed power of 3.3 MW (individual CHP units with range of 35 – 800 kW). In the surveyed WWTPs the 35 000 kWh of electrical power were produced daily what represent 12.7 GWh annually. According to the information from water companies many WWTPs have serious interest in installation or enlargement of production of electrical power on CHP systems (Bodík *et al. 2009*) and to use suitable external biodegradable organic waste materials to increase biogas production.

Food waste is a growing issue, and the disposal of it is controversial, causing increased food prices and the resources required (Mashad & Zhang *2010;* Mata-Alvarez *et at. 2000;* Wang *et al. 2005*) Food waste makes up an estimated 8.4% by weight of municipal solid waste in the United States, and in the UK, each household buys on average 16.5 kg of food a week and throws a third of it away. The food waste includes uneaten food and food preparation leftovers from residences, commercial establishments such as restaurants, institutional industrial sources like school cafeteria, factory lunchrooms, etc. Food waste is the single-largest component of the waste stream by weight in the USA – Americans throw away about 43.6 million tons of food each year that represent 0.4 kg/cap.day. The recent papers on the status of organic waste recycling in the EU estimated total production of 3.5 million tonnes of food waste treated by anaerobic digestion (Kidby *2010*).

Other authors (Cho & Park *1995*) determined the methane yields of different food wastes at 37 °C and 28 days of digestion time. They were 482, 294, 277, and 472 mL/g VS for cooked meat, boiled rice, fresh cabbage and mixed food wastes, respectively, which correspond to 82%, 72%, 73% and 86% of the stoichiometric methane yield, respectively, based on elemental composition of raw materials. (Heo *et al. 2004*) evaluated the biodegradability of a traditional Korean food consisted of boiled rice (10–15%), vegetables (65–70%), and meat and eggs (15–20%) and reported that after 40 days a methane yield of 489 mL/g VS could be obtained at 35 °C. (Zhang *et al 2007*) characterized potential of food waste as a feedstock for anaerobic digestion. The daily and weekly variations of food waste composition over a two-month period were measured. The anaerobic digestibility and biogas and methane yields of the food waste were evaluated using batch anaerobic digestion tests performed at 50 °C. The daily average moisture content (MC) and the ratio of volatile solids to total solids (VS/TS) determined from a week-long sampling were 70% and 83%, respectively, while the weekly average MC and VS/TS were 74% and 87%, respectively. The nutrient content analysis showed that the food waste contained well balanced nutrients for anaerobic microorganisms. The methane yield was determined to be 348 and 435mL/g VS, respectively, after 10 and 28 days of digestion. The average methane content of biogas was 73%. The average VS destruction was 81% at the end of the 28-day digestion test. The results of this studies indicated that the food waste is a highly desirable substrate for anaerobic digesters with regards to its high biodegradability and methane yield.

The objective of this study is to describe the food waste digestion in the laboratory conditions with the aim of characterization of the basic technological parameters such as specific biogas production, methane content in biogas, optimal organic load etc. The next aim of study is to define the influence of food waste doses on quality of rejected sludge water on municipal WWTP, especially, on nitrogen and phosphorus concentration, chemical organic demand (COD), pH, lower fatty acids, etc.

MATERIALS AND METHODS

Description of laboratory equipment

The laboratory modelling of the biogas production from food wastes was realised in the anaerobic reactor (ASIO Bytča, Slovakia) with the total volume 18 L and with operational volume of 13 L (Figure 1). The reactor was warmed up to 37 – 38 °C by thermostat TS – 050 SRCI (MERLIN GERIN) and stirred (IKA RW 14basic). The biogas was carried to biogas flow meter where the production of biogas was measured. The laboratory model was filled with the anaerobic sludge from WWTP Bratislava - Devínska Nová Ves (Slovakia). The initial values of the sludge were: total suspended solids (TS) 13.7 g/L, volatile suspended solids (VS) 54 % and pH 7.18.

Figure 1 Laboratory model of anaerobic reactor

The dosing of the substrate was starting on November 5th, 2008 and stopped on May 18th, 2009. The food wastes (lunch leftovers) from the canteen of Faculty of Chemical and Food Technology of the Slovak University of

Technology Bratislava were used as the single substrate for biogas production. The operator of the university canteen prepares lunches for 600-800 persons daily. Generally the menu includes six main daily meals that ensure sufficient content diversion of the substrate. Every substrate was mixed, hygienised at 70°C during one hour and the values of pH, chemical organic demand (COD), ammonia nitrogen (NH_4-N), total nitrogen (Ntot) and phosphorus (Ptot), total solids (TS) and volatile solids (VS) were measured. Hygienised food waste was stored in refrigerator and consequently used as substrate for digestion during next two-three weeks.

RESULTS AND DISCUSSION

Tested food waste and its basic parameters

The range and average substrate composition are introduced in Table 1. The range in some measured parameters as COD, Ptot, TS, VS and pH is relatively wide. This variability depends on type of used meals, portion of moistures foods (soups, sauces etc.). The nutrient contents, ratio of COD : Ntot : Ptot (500:6.7:1) shows that this tested food waste represents well balanced feedstock for anaerobic digestion with expected high biological degradation in anaerobic condition. The food waste has very high portion of organic (volatile) solids comparable with other studies (Heo *et al. 2004;* Zhang *et al 2007*). These differences in chemical composition between Asian and Central European food waste result from differences in traditional food structure, favourable vegetable base of Asian food compared to the meat and fat base of food in Central Europe. From this point of view the European (probable American, too) food waste is much more appropriate for biogas production.

Table 1 The basic composition parameter of tested food waste

Food waste	Unit	Average	Range
COD	mg/L	245 000	150 000 – 320 000
NH_4-N	mg/L	760	650 – 900
N_{tot}	mg/L	3350	3000 – 3900
P_{tot}	mg/L	500	300 – 800
TS	g/L	130	85 – 300
VS	g/L	120	75 – 270
VS/TS	%	92	91 – 95
pH	-	5.3	4.8 – 8.7

Food waste methanogenic laboratory tests

The laboratory reactor was starting its operation on November 5th, 2008 by addition of the first food waste dose into digestion tank filled with anaerobic sludge. The substrate daily doses were increasing from 20 mL/day up to the final 500 mL/day of food waste. The initial value of the volumetric reactor load was Bv = 0.51 g VS/L.day, the load was gradually being increased to the value of 3 g VS/L.day (Figure 2). During the highest substrate doses (500 mL/day and 3.0 g VS/L.day) the problems with stability of digestion process started (pH values below 6.5 and biogas production decrease) and after half year the laboratory test was stopped.

The biogas production was monitored daily from the beginning of the process. The volume of the produced biogas was increasing gradually depending on the increasing reactor load. The highest production of the biogas 55.4 L/day was reached in 147th day at reactor load 3 g VS/L.day. The average specific biogas production from food wastes was around 930 L of biogas from 1 kg VS of food waste during the whole duration of the measurements. The biogas analyses were realised on the gas analyser GA1125 (Geotechnical Instruments) and the average methane concentration in biogas was 52.5 %.

Co-digestion of food waste with WWTP sludge

With the aim of food waste co-digestion under laboratory conditions the new phase of tests was started. The mixture of real sludge (primary and excess sludge from WWTP Bratislava) and food waste was used. During the initial phase of the tests (70 days) only real sludge (500 mL/day) as feedstock for anaerobic digestion was applied. In the second phase of the tests the small doses of food waste were added to the real sludge. The doses of food waste were slowly increased (from 0 mL/day up to 50 mL/day on the end of tests) during the second phase of tests. The values of volumetric load of reactor started at 0.7 g VS/L.day, during the addition of food waste the reactor load was increased up to 1.3 g VS/L.day (Figure 3).

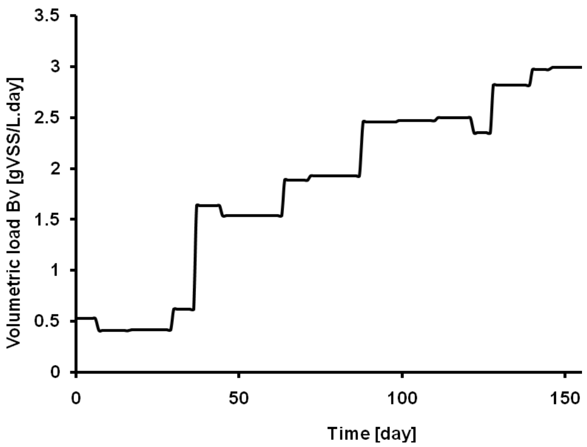

Figure 2 Development of organic load during the methanogenic laboratory test.

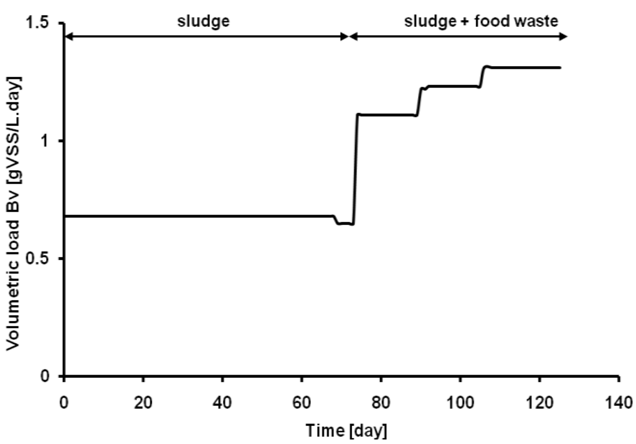

Figure 3 Development of organic load during the co-digestion laboratory test.

The biogas production and its quality were monitored during the whole duration of the co-digestion tests. The volume of the produced biogas reached in average 4.98 L/day in the first test phase, what represents specific biogas production of 0.5 L/g VS of sludge. The average methane content in biogas ranged between 60-65%. The biogas production seriously increased after adding of 50 mL/day of food waste up to 10.02 L/day, what represents specific biogas production 0.7 L/g VS of food waste in average. The methane contribution in biogas decrease to 55-60% compared to the previous phase of the test.

The addition of food waste to digestion process in WWTP can seriously increase the biogas production. The food waste dose e.g. of 25 m^3 can produce ca 2100-2800 m^3 of biogas, which represents ca 100% increase of daily biogas production in WWTP with capacity of 100 000 PE (of course, with free technological and technical capacities of WWTP).

The influence of food waste doses on rejected sludge water quality is one the most important restriction factor for application of food waste in real WWTPs. Increase of COD, N_{tot}, P_{tot} in the rejected water could affect the biological treatment process of wastewater mainly in nutrients removal strategy. The results of rejected water composition after digestion processes from previous laboratory tests (methanogenic and co-digestion tests) with using of food waste as digestion substrate are presented in Table 2. From the measured data it is evident that doses of food waste increase all technologically important parameters of rejected sludge water. On the other hand, only the volume (or organic load) of food waste dosed into digestion tank of WWTP is the crucial parameter for affecting the rejected sludge water quality. The influence of food waste dosing into digestion tank of three municipal WWTPs on increase of nitrogen concentration in influent wastewater is shown in the Figure 4.

Table 2 The quality of rejected water in various laboratory tests depending on food waste doses

		methanogenic tests	co-digestion tests	
Parameter	Unit	food waste	sludge	sludge + food waste
COD	mg/L	625	285	325
NH_4-N	mg/L	600	580	660
N_{tot}	mg/L	1050	600	710
P_{tot}	mg/L	37.5	25.5	28.0
VFA	mg/L	620	300	410
pH	-	8.3	8.2	7.8

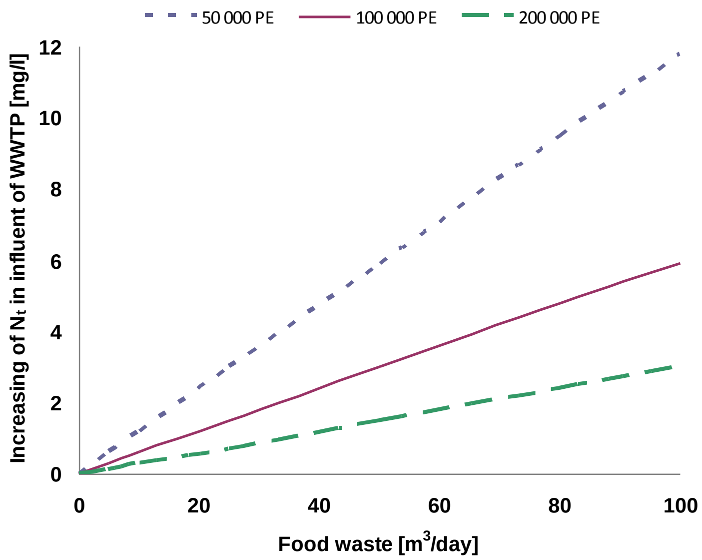

Figure 4 Influence of food waste doses into digestion tank on increasing of total nitrogen concentration in influent wastewater.

The addition of food wastes to WWTP with the capacity of about 200 000 PE could not cause important influence of the treatment process. If the volume of the added food waste was less that 50 m^3/day, the change of wastewater quality would be negligible (N_{tot} increase of 1.5 mg/L). At the dose 50 m^3/day of food wastes the increase of the nitrogen concentration in inflow to WWTP with capacity of 100 000 PE represents about 2.9 mg/L. The same dose of food waste into smaller WWTP (50 000 PE) can cause a serious problem with nitrogen removal (N_{tot} increase of 5,9 mg/L) which should be eliminated only with upgrading of denitrification process on WWTP.

CONCLUSIONS

The laboratory study presents food waste as appropriate easily biodegradable substrate for anaerobic digestion process. The range of parameters as COD, Ptot, TS, VS and pH is relatively wide and depends on type of used meals, portion of moistures foods (soups, sauces etc.). The nutrient contents and balances between COD : N_{tot} : P_{tot} (500:6.7:1) show that tested food waste represents well balanced feedstock for anaerobic digestion with expected high biological degradation in anaerobic condition.

The biogas production during the long-term tests with only food waste as feedstock was around 930 L of biogas from 1 kg VS of food waste with average methane contents of 52.5 %. The average specific biogas production of 700 L/kg VS of food waste was measured in the laboratory system of co-digestion food waste with treatment sludge. Addition of food waste to sludge causes decrease of methane content from 60-65% (only sludge) to 55-60% (sludge + food waste).

Influence of food waste dosed into digestion tank of WWTP on rejected sludge water quality was also investigated. Increase of food waste dose could affect nitrogen balances in influent wastewater mainly in WWTPs with low treatment capacity.

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References

Bodík, I., Hutňan, M., Sedláček, M. & Kubaská, M. (2009) Biogas production on Slovak municipal wastewater treatment plants. *Vodní hospodářství* **59**(11), 1–3 (in Slovak).

Cho, J.K. & Park, S.C. (1995) Biochemical methane potential and solid state anaerobic digestion of Korean food wastes. *Bioresource Technol.* 52 (3), 245–253.

El-Mashad, H.M. & Zhang, R. (2010) Biogas production from co-digestion of dairy manure and food waste. *Bioresource Technology* **101**, 4021-4028.

Heo, N.H., Park, S.C. & Kang, H. (2004) Effects of mixture ratio and hydraulic retention time on single-stage anaerobic co-digestion of food waste and waste activated sludge. *J. Environ. Sci. Health* A39 (7), 1739–1756.

Kidby, D. (2010) Food, glorious food. *Waste Management World*, January-February 2010, 30-33.

Mata-Alvarez, J., Macé, S. & Llabrés, P. (2000) Anaerobic digestion of organic solid waste. An overview of research achievements and perspectives. *Bioresource Technology* **74**, 3-16.

Wang, J.Y., Zhang, H., Stabnikova, O., Ang, S.S. & Tay, J.H. (2005) A hybrid anaerobic solid – liquid system for food waste digestion. *Wat. Sci. & Techn*. **52** (1-2) 223-228.

Zhang R., El-Mashad H.M., Hartman K., Wang F., Liu G., Choate Ch. & Gamble P. (2007) Characterization of food waste as feedstock for anaerobic digestion. *Bioresource Technology* **98**, 929-925.