New mixtures and technologies for biogas production at biogas plants of agricultural type processing livestock slurry

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Abstract: The basis of the biogas production in agriculture is the processing of waste agricultural products (particularly excrements of farm animals but also phytomass). Different but rather similar is the biogas production from biologically degradable municipal waste (BDMW) and biologically degradable industrial waste (BDIW) coming mainly from food industry. The processing of these wastes in agricultural biogas stations could significantly improve their economy. It is necessary to note that all these biogas stations differ from the wastewater cleaning plants where municipal sludge water from public sewers is processed. The municipal sludge water processing to biogas by anaerobic fermentation is a classical technology introduced all over the world. At present, about 100 wastewater cleaning plants operate in the Czech Republic using regular sludge processing into biogas. Electricity produced is utilised mainly for the needs of own operation of waste water treatment plant (WWTP), partly it is sold into public power net. The heat energy is used for heating in the process and its surplus is utilised for operational and administrative facilities. Usually, the heat and electricity quantities produced do not cover the wastewater cleaning plant operation. Agricultural biogas stations and biogas stations for BDMW processing provide considerably higher gas yields because they work with higher dry matter contents in substratum, i.e. 8–12% (compared with waste water treatment plants – 2–6%), and are able to produce high gas surpluses for following applications. Frequently discussed issue are the processing of slaughter waste and grass (or public green areas at biogas stations).

Keywords: slaughter waste; biogas plant; biogas production

The base of the biogas production in agriculture is the processing of waste agricultural products (mainly livestock excrements but also phytomass), other possibilities of the biogas production are represented by biologically degradable municipal and industrial wastes, particularly from food industry plants. Currently, the attention is concentrated on the slaughterhouse waste processing. The processing of that waste in agricultural biogas plants could significantly improve their economy.

Since recent years, animal by-products as well as slaughterhouse waste and wastewater have not been considered as waste anymore. We have realised that they are feedstocks able to be treated in order to gain their energy potential. With a rising threat of diseases such as bovine spongiform encephalopathy (BSE) in cattle, and with a strickter legislation and an effort to use non-waste technologies with an effective energy gain, a demand is taking place on deeper research activities regarding this problems.

Anaerobic digestion has become an established and proven technology as a means of managing solid as well as liquid organic wastes.

In this chapter, some results are quoted of research experiments and information regarding anaerobic digestion of animal origin by-products ABP:

The effect of hydraulic retention time (HRT) and loading on anaerobic digestion of poultry slaughter wastes was studied by Salminen and Rintala (2002). The experiment was carried out in semi-continuously fed laboratory-scale digesters at 31°C. The effect on the process performance was highly significant: Anaerobic digestion appeared feasible with a loading of up to 0.8 kg volatile solids (VS)/m^3 × day and HRT of 50–100 days. The specific methane yield was high, from 0.52 to 0.55 m^3/kg (VS_{added}).

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On the other hand, at a higher loading in the range from 1.0 to 2.1 kg (VS)/m^3 × day and shorter HRT in the range from 25 to 13 days, the process appeared inhibited and/or overloaded, as indicated by the accumulation of volatile fatty acids (VFA) and long-chain fatty acids (LCFA) as well as a decline in the methane yield. However, the inhibition was reversible. Nitrogen in the feed, ca. 7.8% of the total solids (TS), was organic nitrogen with little ammonia present, whereas in the digested material ammonia accounted for 52–67% (up to 3.8 g/l) of total nitrogen. The TS and VS removals amounted to 76% and 64%, respectively.

A new generation mathematical model called <METHANE> was modified in order to describe the system dynamics in slaughter waste degradation (Vavilin 2003). Salminen *et al.* (2000) used this modified version for studying anaerobic batch degradation of solid poultry slaughterhouse wastes.

Broughten *et al.* (1998) studied anaerobic digestion of sheep tallow. The experiment was carried out in batch reactors operating at mesophilic (35°C) and thermophilic (50°C) temperatures with sheep tallow at levels of up to 59% of the volatile solids. The tallow was rapidly fermented to LCFA and VFA at 35°C but was refractory at 50°C. Oleic acid was fermented to palmitic, stearic, and acetic acids. Methanogenesis was delayed by characteristic adaptation periods before LCFA and VFA were completely degraded. This demonstrated that wastes with high lipid contents are amenable to stabilisation by mesophilic batch digestion.

Dohányos *et al.* (2003) studied two methods of meat and bone meal (MBM) treatment – pyrolysis and anaerobic digestion and their combination. The preliminary experiments of anaerobic digestion were carried out with classically produced MBM at 140°C and MBM pyrolysed at 200°C and 285°C. The biogas yield was determined by batch experiments with digested sludge as inoculum. The results showed very good biodegradability of MBM and MBM pyrolysed at 200°C, the biogas production reached 0.37 l and 0.452 Nm^3/kg of dry matter respectively.

Farinet and Forest (2003) mentioned brief descriptions of two slaughterhouse treatment plants based on anaerobic digestion in Africa. One is located in Senegal, the other in Egypt. Both have equipments for the digest composting. The authors expect a rising further development of this combined treatment of slaughterhouse waste in Africa, mainly because of the high levels of energy price and compost demand.

Ashare *et al.* (1983, in Straka *et al.* 2003) studied available values of biological oxygen demand (BOD) of various types of waste from meat processing industry. They found out that the available (BOD) of this waste has a great potential, e.g. for cattle – blood has 2.3 kg (BOD)/t LWK (live weight killed), intestinal content has 2.5 kg (BOD)/t LWK; for poultry – 15.3 kg (BOD)/t LWK. The specific methane production obtained with this waste is very high due to the high content of fat.

MATERIAL AND METODS

Material and methodology of slaughterhouse waste processing

The experiments were conducted based on one-stage batch anaerobic digestion with a batch of 5% dry matter. The experiments were carried-out under mesophilic and thermophilic conditions in two serials varying in the retention times (experiment 1 and 2).

Material

The following materials were available:

Slaughterhouse waste – from Kostelecké uzeniny, stock-company in Kostelec (nearby Jihlava)

dry matter of poultry crushed bones 9.8%
dry matter of pig tendons 15.2%

According to the Directive EC No. 1774/2002, all these materials belong to category 3.

Cattle and pig slurry in the ratio 1/1 – obtained from Rabbit, stock company, Trhový Štěpánov. The pig slurry is classified as material of category 2 according to the Directive EC No. 1774/2002.

Steady aqueous remainder after anaerobic digestion – utilised as inoculum; obtained from the biogas plant of the Rabbit company, Trhový Štěpánov.

Material preparation in accordance with the Directive EC No. 1774/2002

The poultry crushed bones and pig tendons are classified as material of category 3. In Annex VI, Chapter II of that Directive, the standards are presented of the processes for individual categories.

The poultry crushed bones and pig tendons were cut to fractions of 12 mm size. The sanitation was performed in an autoclave. The material was processed at the temperature of 70°C for 60 minutes.

Batch preparation – small reactors of 3 l volume

Slurry and digestion product were blended in the ratio 1/1 – share 1.

Ratios of substrates in individual batches are presented in Table 1.

Batch material composition – small reactors of 3 l volume

Batch material composition is presented in Table 2.

Table 1. Ratio of substrates in individual batches (% by weight)

Reactor	Share 1	Poultry crushed bones	Pig tendons
1a	100	0	0
2a	90	10	0
3a	80	20	0
4a	70	30	0
5a	60	40	0
6a	90	0	10
7a	80	0	20
8a	70	0	30
9a	60	0	40

Table 2. Batch material composition of small reactors in both experiments (g)

Reactor	Share 1	Poultry crushed bones	Pig tendons	Water
1a	1250.0	0.0	0.0	750.0
2a	803.6	89.3	0.0	1107.1
3a	555.6	138.8	0.0	1305.6
4a	397.7	170.5	0.0	1431.8
5a	288.5	192.3	0.0	1519.2
6a	1034.5	0.0	114.9	850.6
7a	851.1	0.0	212.7	936.2
8a	693.1	0.0	297.1	1009.8
9a	555.6	0.0	370.3	1074.1

Batch preparation – big reactors of 100 l volume

Slurry and digestion product were blended in ratio 1/1.

Ratios of substrates in individual batches are presented in Table 3.

Batch material composition – big reactors of 100 l volume

Big reactors were filled with batches given in Table 4.

Hydraulic Retention Time (HRT) is in Table 5.

Biogas production (Q) measuring

Biogas production in small reactors was measured by means of gasholders constructed in Research Institute of Agricultural Engineering (RIAEng).

Table 3. Ratio of substrates in individual batches, big reactors, experiment 1 (mass %)

Reactor	Share 1	Poultry crushed bones	Pig tendons
1b	70	30	0
2b	70	0	30

Table 4. Ratio of substrates in individual batches, big reactors, experiment 2 (mass %)

Reactor	Share 1	Poultry crushed bones	Process
1b	70	30	mesophilic
2b	70	30	thermophilic

Biogas production in big reactors was measured by means of gasometer of type G 01, manufacturer Spectrum, Ltd., Skuteč (CZ), with the following parameters:

Q_{min} = 0.01 m^3/h, Q_{max} = 0.15 m^3/h

Determination of biogas chemical composition

Chemical composition of the biogas produced was determined by means of the analyser AIR LF (manufacturer ASEKO, Ltd., Vestec near Prague, CZ).

The analyser is specified for the analysis of landfill gas and biogas. Methane and carbon dioxide concentrations are determined by means of the infrared radiation; for oxygen concentration determination, the electro-chemical sensor is used.

Biogas chemical composition was determined once in 24 hours.

Chemical analysis

Chemical analysis of the stable remainder was provided by agro-chemical laboratory of RIAEng (Prague) and RICP (Research Institute of Crop Production, Chomutov). The following methods were used for chemical analysis of the stable remainder:

– Kjeldahl's method of total N content determination

Table 5. Hydraulic Retention Time (HRT in days)

	Experiment 1	Experiment 2
Small reactors	26	37
Big reactors	37	33

– Spectro-photometric P determination
– Atomic Emission Spectrophotometry for K and Ca contents determination
– Spectrophotometry for NH_4^+ determination

Microbiological analysis

The stable remainder sample was tested for the occurrence of *Salmonella* and *Enterobacteriaceae* bacteria in microbiological laboratory of the State Health Institute in Prague. The microbiological analysis methods were in compliance with the requirements given by the EC Directive No. 1774/2002.

Outputs

pH – values
  – Batches before processing
  – Stable remainder
Dry matter determination
  – Batches before processing
  – Stable remainder
Losses determination by annealing
Biogas cumulative production
Chemical composition of produced biogas
Methane cumulative production
N, P, K and Ca contents in the remainder after anaerobic digestion (AD)
Ammonia content in the remainder after (AD)
Salmonella and *Enterobacteriaceae* occurrence in the remainder after (AD)

RESULTS AND DISCUSSION

In this part the results are presented of both experiments. The following parameters were monitored:
– Biogas production
– Methane content in produced biogas
– Physical-chemical analysis
– Microbiological analysis

Reactor 1 was used in both experiments as the control unit – the batch did not contain any additive material (0%). In biological experiments, the control sample outputs served as the referential material enabling to estimate possible negative effects (contamination, instable temperature conditions, low-quality inoculum etc.) during the experiment.

The control sample in experiment 1 showed, a relatively high biogas production as compared with experiment 2.

Biogas production

Biogas production was measured every day, however, for a better understanding the cumulative production is presented for each experiment. The measurement results refer to the small reactors for individual concentrations of the additive materials (poultry crushed bones and pig tendons).

Each chapter contains the comparison of both experiments parameters:
1 kg of dry matter. This parameter expresses the course of the process.
1 kg of added organic matters. This parameter expresses the effectiveness of the process. It also

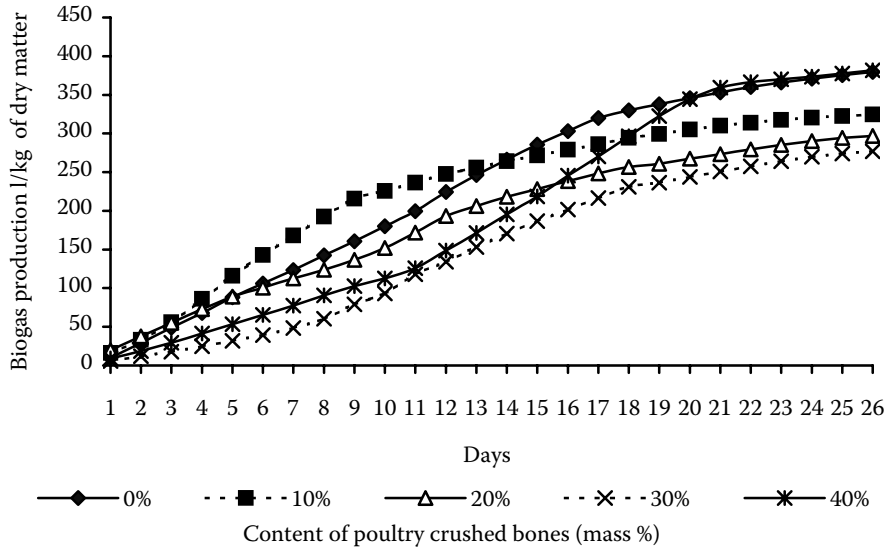

Figure 1. Biogas cumulative production (l/kg of dry matter), small reactors, poultry crushed bones, experiment 1

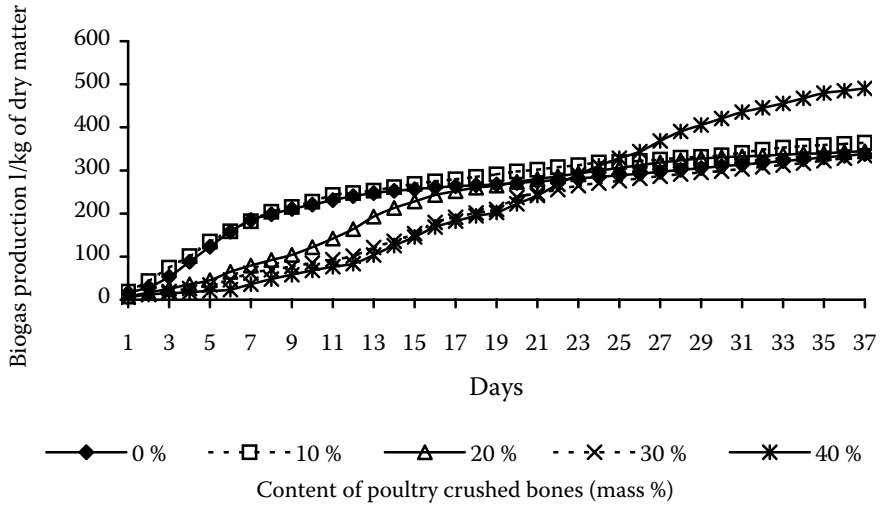

Figure 2. Biogas cumulative production (l/kg of dry matter), small reactors, poultry crushed bones, experiment 2

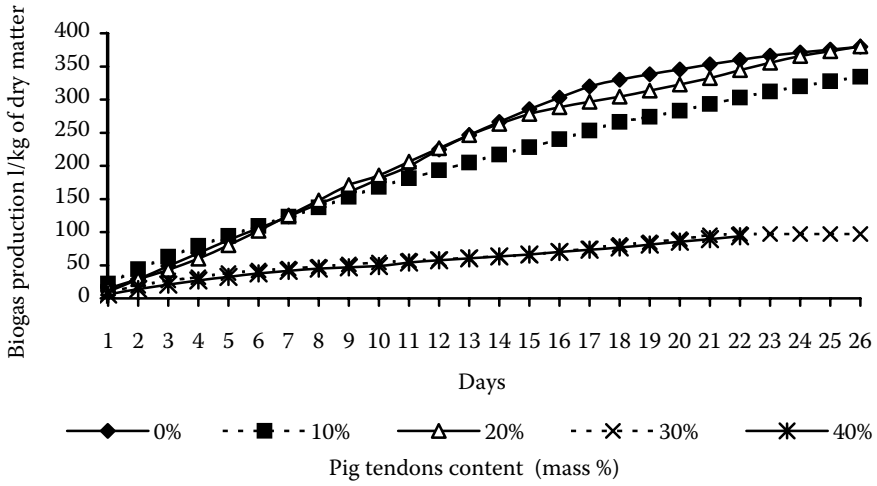

Figure 3. Biogas cumulative production (l/kg of dry matter), small reactors, pig tendons, experiment 1

defines the transformation of the organic matter to biogas. This value is more important from the view of organic matter proportion in the batch.

Poultry crushed bones – small reactors

Biogas cumulative production related to dry matter

The investigated samples contained crushed bones in concentrations of 10%, 20%, 30%, and 40%, and pig tendons in the same concentrations. In Figures 1–4 are shown the results of the experiments obtained with crushed bones and pig tendons within the mesophilic area. The experiments courses were very similar but varied in certain details. The samples were processed in one-stage reactors under the mesophilic and thermophilic conditions (the courses in the thermophilic conditions are not presented because they are very similar, only the retention time is shorter). In the mesophilic area, 2 experiments were carried out differing in the retention times (26 and 37 days).

The samples composition including crushed bones seems to be optimal from the point of view of the biogas production and methane content. The highest biogas cumulative production was reached with the sample containing 40% of crushed bones (381.5 l/kg of dry matter and 561.0 l/kg of dry matter) after 26 days.

The samples containing 10% and 20% of pig tendons demonstrated a satisfactory production of biogas and methane. The best result was reached with the sample containing 10% of pig tendons (460.5 l/kg of dry matter a 641.4 l/kg of dry matter) after 26 days of retention time. The samples containing 30% and 40% of pig tendons were characterised by a low biogas production with a high content of methane (from 70% to 80%). These samples exhibited problems connected with foaming. The big reactors confirmed the results obtained with the small reactors, only the foaming

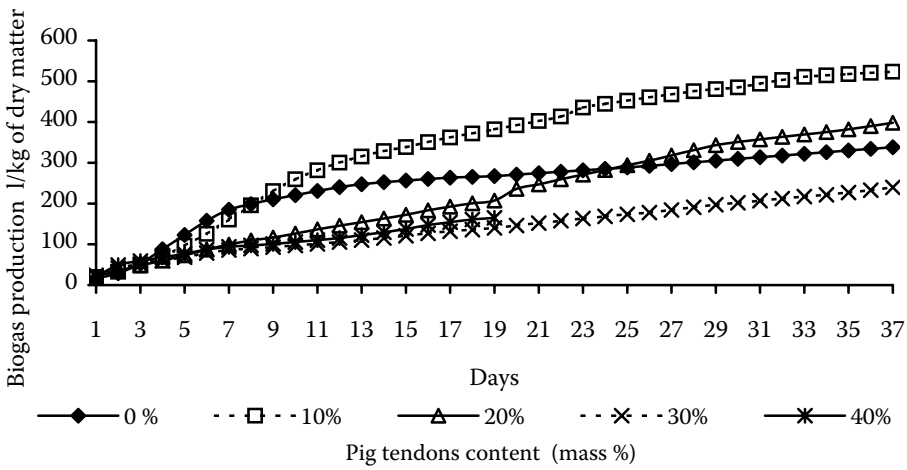

Figure 4. Biogas cumulative production (l/kg of dry matter), small reactors, pig tendons, experiment 2

of samples was not so intensive. The thermophilic process accelerated the beginning of the biogas maximum production by 10 days.

The stable remainder after the anaerobic digestion was analysed from both chemical and microbiological aspects and its suitability for the land application was proved.

Therefore, it may be stated that the poultry crushed bones and pig tendons are suitable materials for anaerobic digestion provided that the correct weight proportions in the fermented mixture are kept.

CONCLUSIONS

The increase of the biogas plants effectiveness can be achieved by the use of the slaughterhouse waste and similar materials from food processing, including the cooking waste. The stable remainder after the anaerobic digestion of the slaughterhouse waste was analysed from both chemical and microbiological points of view and its health perfection and suitability for the land application ranked it as an excellent fertiliser. Nevertheless, the slaughterhouse waste processing in the biogas plant needs the installation of a unit for thermal adaptation of the input substratum.

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Abstrakt

Kára J., Pastorek Z., Mazancová J., Hanzlíková I. (2009): **Nové směsi a technologie výroby bioplynu v bioplynových stanicích zemědělského typu, zpracovávajících kejdu z chovů hospodářských zvířat.** Res. Agr. Eng., **55**: 62–68.

Základem výroby bioplynu v zemědělství je zpracování zemědělských odpadních produktů (částečně exkrementů hospodářských zvířat, ale i zelené biomasy). Rozdílná je výroba bioplynu z průmyslových odpadních vod a z měst-

ských kalových vod. Zpracování komunálních kalových vod anaerobní fermentací na bioplyn je klasickou technologií, používanou na celém světě. V současnosti je podle odhadu v ČR v provozu 100 čistíren odpadních vod (ČOV) s tímto předpisovým zpracováním kalů na bioplyn. Vyrobená elektrická energie se využívá zejména pro potřeby vlastního provozu, částečně se prodává do sítě. Tepelná energie je využívána pro ohřev procesu, případné přebytky jsou využity pro vytápění hospodářských a administrativních objektů ČOV. Vyráběné teplo a elektrická energie však zpravidla nestačí pro pokrytí potřeb provozu ČOV. Zemědělské bioplynové stanice a bioplynové stanice na zpracování biologicky rozložitelných komunálních odpadů (BRKO) mají podstatně větší výtěžnost plynu, neboť pracují s vyššími koncentracemi sušiny v substrátu 8–12 % (proti ČOV kde jde o 2–6 %) a jsou schopné vyrábět značné přebytky plynu pro následné využití. Všechny tyto bioplynové stanice se liší od čistíren odpadních vod, kde se zpracovávají komunální kalové vody z obecních kanalizačních systémů. Velmi často se uvažuje o kombinované výrobě bioplynu z jatečních odpadů a trávy (nebo odpadů z péče o veřejnou zeleň).

Klíčová slova: jateční odpady; zařízení na výrobu bioplynu; výroba bioplynu

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