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The impact of mesophilic and thermophilic anaerobic digestion on biogas production

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ABSTRACT

Purpose: of this paper is to compare mesophilic and thermophilic anaerobic digestion of three maize varieties. Parameters such as biogas production and biogas composition from maize silage were measured and calculated. The amount of biogas production (methane) was observed by the mini digester.
Design/methodology/approach: Biogas production and composition in mesophilic (35 degrees C) and thermophilic (55 degrees C) conditions were measured and compared. The measurements were performed with mini digester according to DIN 38414 part 8. We used three different maize varieties (NK PAKO, PR34N43 and RAXXIA).
Findings: Biogas yields ranged between 315 - 409 Nl kg VS^{-1} in mesophilic conditions and 494 – 611 Nl kg VS^{-1} in thermophilic conditions. The highest biogas yield was in case of NK PAKO (611 NI kg VS^{-1}) in thermophilic conditions. The lowest biogas yield was in case of PR34N43 (315 NI kg VS^{-1}) in mesophilic conditions. Biogas quality produced in thermophilic temperature range is better than biogas quality produced in mesophilic temperature range. Thermophilic digestion is 4 times more intense, has higher VSS removal efficiency and yields more biogas.
Research limitations/implications: Thermophilic stabilization of energy plants at 55°C is truly economical, more biogas is produced. The only disadvantage of thermophilic stabilization is that more energy is used for heating fermenters. Therefore, further researches are necessary.
Practical implications: For biogas plants with mesophilic digesters we suggest an upgrade of existing mesophilic digesters (35°C) to thermophilic digesters (55°C), which is an economically beneficial solution compared to construction of additional mesophilic digesters.
Originality/value: The mini digester for biogas production was built as special equipment. It can be used in mesophilic and thermophilic conditions. The quality of the produced biogas is determined with a gas analyser GA 45.
Keywords: Technological devices and equipment; Mini digester; Anaerobic digestion; Temperature range

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1. Introduction

Anaerobic digestion is the most widely used method of organic waste disposal due to its high performance in volume reduction and stabilization and the production of biogas that makes the process profitable. However, biological hydrolysis, which is the rate-limiting step for the anaerobic degradation [1] has to be improved to enhance the overall process performance and to reduce the associated cost. Several mechanical, thermal, chemical, or biological pretreatment methods have been considered to improve hydrolysis and anaerobic digestion performance. These pretreatments result in the lysis or disintegration of cells [2, 3] and release of intracellular matter that becomes more accessible to anaero-bic micro-organisms [4], thus improving anaerobic digestion [1].

Anaerobic fermentation significantly reduces the total mass of wastes, generates solid or liquid fertilizer and yields energy. It can be maintained at psychrophilic (12-16 °C, e.g. in landfills, swamps or sediments), mesophilic (35-37 °C, e.g. in the rumen and in anaerobic digester) and thermophilic conditions (55-60 °C; e.g. in anaerobic digesters or geothermally heated ecosystems). Disadvantages of thermophilic anaerobic fermentation are the reduced process stability and reduced dewatering properties of the fermented sludge and the requirement for large amounts of energy for heating, whereas the thermal destruction of pathogenic bacteria at elevated temperatures is considered a big advantage [5]. The slightly higher rates of hydrolysis and fermentation under thermophilic conditions have not led to a higher methane yield. [6, 7] reported no significant change in the total methane yield from organic matter for fermentation temperatures ranging from 30 °C to 60 °C.

Compared to mesophilic fermentation conditions, at higher temperatures the pH increased through a reduced solubility of carbon dioxide, leading to a higher proportion of free ammonia. Ammonia is generated during anaerobic degradation of urea or proteins. In the organic fraction of household waste the organic nitrogen that was released as ammonia during anaerobic fermentation amounted to 2.15 g N/l [8].

Sludge digestion is the most common process for waste sludge treatment. The anaerobic mesophilic process is the most widely used. Less common is the use of aerobic digestion. Generally, the anaerobic process is still the subject of research, due to the biogas evolved as a by product of such a process. Degradation of volatile suspended solids in the conventional mesophilic anaerobic process is about 40% at retention times between 30 an 40 days [9]. For achieving successful sludge digestion several physical and chemical factors must be considered. The most important physical factor is temperature. In anaerobic digestion there are generally two temperature ranges. Anaerobic sludge digestion can occur in the mesophilic range (35 °C), which is more usual, or in the thermophilic range (55 °C), which is less common. It is important that the temperature remains constant. Each specific methane forming bacterium has an optimum for growth. Methane formers can generally be divided into two groups, each group operates in the temperature range where the temperature is the most convenient for their growth. For instance, the mesophilic temperature range is optimal for a large number of methane forming microorganisms. For other groups of microorganisms optimal temperatures are in the thermophilic range. If the temperature fluctuates too fast, no methane formers can achieve a high stable population. A smaller microorganism population means reduced stabilization and reduced methane formation. The range between the mesophilic and thermophilic range has not yet been entirely researched. However, Figure 1 [10] shows biogas production in dependence of temperature clearly in two ranges, first peak is in mesophilic temperature range, second in thermophilic range. These two peaks shown as biogas production actually reflect methane forming bacteria activity.

In this study, we compare the fermentation of the wet organic fraction of three maize varieties in laboratory scale reactors under meso- and thermophilic conditions, concentrating on the biogas production and biogas composition in both conditions.

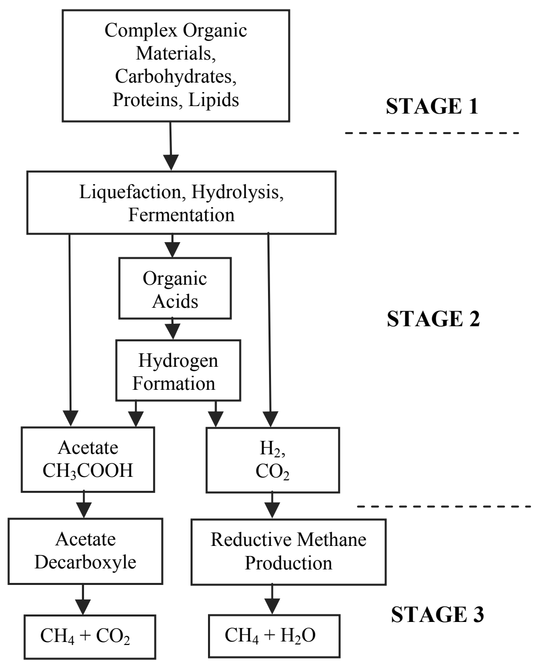

Fig. 1. Multistep methanogenesis in anaerobic digestion

2. Description of the approach, work methodology, materials for research, assumptions, experiments etc

Measurements were conducted according to DIN 38 414, part 8 [11, 12]. Parameters such as biogas production and biogas composition from maize silage were measured and calculated in mesophilic (35 °C) and thermophilic (55 °C) conditions. We used three different maize varieties (NK PAKO, PR34N43 and RAXXIA).

The mini digester for biogas production was built as special equipment. The quality of the produced biogas is determined with a gas analyser geotechnical instrument GA 45.

2.1. Mini digester for biogas production

The mini digester is used for laboratory tests. The mini digester consists of twelve units and serves to produce the biogas from various energy crops and other organic waste material. Three tests with three repetitions simultaneously are possible, whereas three units serve for the control (inoculum). During the test the biogas production must be read daily. The volume produced is let out in case of each reading, each day at the beginning of test, later on every two or three days, when the gas formation diminishes [13, 14].

Mini digester comprises twelve gas cells (figure 2). Each cell consists of a reaction vessel (500 ml fermenter) and a well closed gas pipe. The gas pipe - eudiometer is of 350 ml size and contains the confining liquid. It is connected to the levelling vessel with solution. The biogas produced in fermenters supplants the confining liquid in the gas pipe into the outside levelling vessel of 750 ml volume. The gas produced is read on the gas pipe. The fermenters are connected with the glass gas pipe and submerged into water with constant temperature 35+/-1 degrees C for mesophilic anaerobic digestion and 55+/-1 degrees C for thermophilic anaerobic digestion.

Fig. 2. Mini digester for biogas production

The biogas produced contains 50 - 75% of methane, 10 - 40% of carbon dioxide and other matters (O_2, H_2, H_2S, N_2, NH_4,...) [15]. Oxygen is an indicator of anaerobic fermentation and the level of oxygen must be under 1%. The exact composition is determined by the gas detector GA 45.

2.2. Maize for anaerobic digestion

The following maize varieties were included in the experiments:

- NK PAKO (FAO 440),
- PR 34N43 (FAO 580),
- RAXXIA (FAO 420).

Maize was chopped after harvest and then mixed in certain ratios, prior to the ensiling process. Particle size was 2.0–4.0 mm.

In course of the vegetation period, specific biogas yield and biogas quality during anaerobic digestion in eudiometer batch experiments were determined for all varieties. Whole maize crops were anaerobically digested and biogas yields were compared.

2.3. Measuring biogas production

The biogas produced is collected in an equilibrium vessel and the biogas production is monitored every day. A water bath tempers the digesters. The substrates are mixed every day for 10 min.

Biogas production is given in norm litre per kg of volatile solids (Nl (kg VS) $^{-1}$), i.e. the volume of biogas production is based on norm conditions: 273 K, and 1013 mbar [11]. Biogas quality (CH_4, CO_2, O_2) was analysed 10 times in course of the 5-week digestion. Each variant was replicated three times and then the average biogas production was calculated. Biogas production from inoculum alone was measured as well and subtracted from the biogas production that was measured in the digesters that contained inoculum and biomass. As inoculum we used actively digested pig manure slurry, which was collected from biogas plant that digests energy crops (maize, millet), filtered and used as inoculum to prepare substrate/inoculum ratios. 15 grams of substrate were digested together with 385 grams of inoculum.

Substance and energy turnover during anaerobic digestion were measured in 0.5 l eudiometer batch digesters at constant temperature 35 +/- 1 degree C and 55 +/- 1 degree C. Biogas yields and biogas composition from each treatment were measured in three replicates. Hydraulic residence time was 35 days.

Figure 3 shows substrate/inoculum ratio in 500 ml fermenter.

Fig. 3. Substrate/inoculum ratio in 500 ml fermenter

3. Description of achieved results of own researches

The last phase of the experiment was to determine dry matter and organic substance of maize hybrids by drying. To determine the specific weight of biogas (Vs) also these two data are needed. We determined the dry matter by drying 100 grams of maize silage in the drier. After drying 38.12 grams of dry weight of the hybrid NK PAKO are obtained. The rest of the substance is then crushed and burn in a laboratory oven for 6 hours at 550 º C. The rest of the substance is actually inorganic substance, which amounts to 1.9 grams, therefore, the loss due to annealing is 98.1%. That means 98.1% of organic substance.

Table 1 shows the results of analysis, dry matter and organic substance, of three maize varieties NK PAKO, PR 34N43 and RAXXIA.

Table 1.
The results of analysis for maize varieties

Maize variety	Dry matter (%)	Organic substance (%)
NK PAKO	38.12	98.1
PR 34N43	35.42	98.4
RAXXIA	34.43	98.7

3.1. Biogas production in mesophilic temperature range

Biogas production was measured during 5 – week digestion. The highest biogas yield at mesophilic temperature range was achieved for maize variety NK PAKO, 409 Nl kg VS^{-1}. The lowest biogas yield was in case of maize variety PR 34N43, 315 Nl kg VS^{-1}. Biogas production in mesophilic temperature range from three maize varieties is shown in Table 2.

Biogas production of maize variety NK PAKO in norm litre per kg of volatile solids (Nl $(kg\ VS)^{-1}$) during 5- week digestion in mesophilic temperature range is shown in Figure 4.

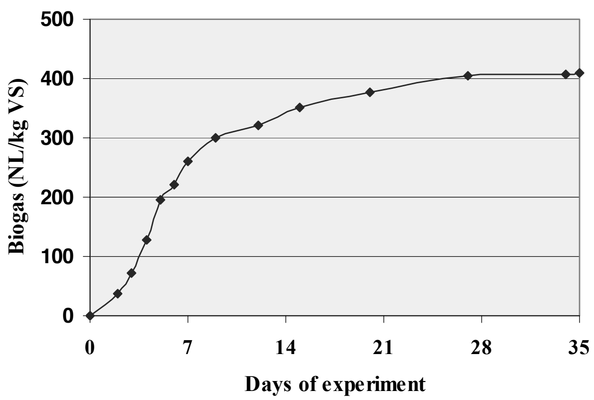

Fig. 4. Biogas production of maize variety NK PAKO during 5–week digestion

Biogas production of maize variety PR 34N43 in norm litre per kg of volatile solids (Nl $(kg\ VS)^{-1}$) during 5- week digestion in mesophilic temperature range is shown in Figure 5.

Table 2.
Biogas production in mesophilic temperature range

Maize variety	Biogas production (Nl/kg VS)
NK PAKO	409
PR 34N43	315
RAXXIA	357

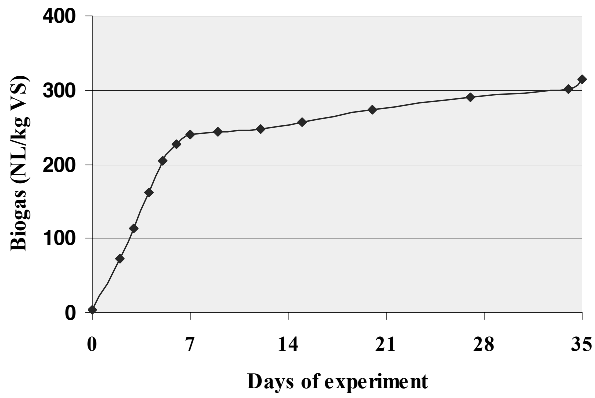

Fig. 5. Biogas production of maize variety PR 34N43 during 5–week digestion

Biogas production of maize variety RAXXIA in norm litre per kg of volatile solids (Nl $(kg\ VS)^{-1}$) during 5- week digestion in mesophilic temperature range is shown in Figure 6.

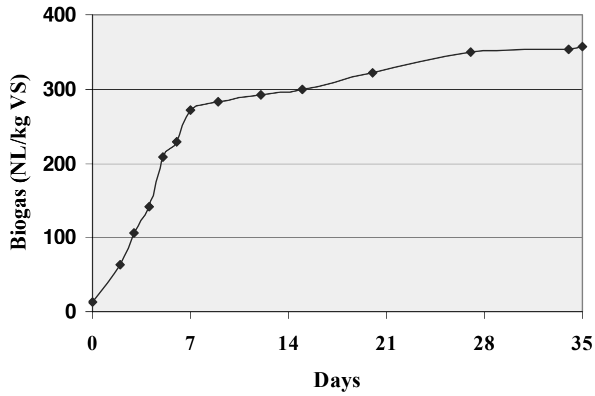

Fig. 6. Biogas production of maize variety RAXXIA during 5–week digestion

In the mesophilic temperature range most of the biogas is produced in the first ten days of the experiment, after two weeks the anaerobic digestion is mostly finished. After 35 days the amount of biogas is very low.

3.2. Biogas production in thermophilic temperature range

In the thermophilic temperature range most of the biogas is produced in the first week of the experiment, after twenty days the anaerobic digestion is mostly finished. After 35 days the amount of biogas is very low. Major differences in the production of biogas at mesophilic and thermophilic temperature range occur in the first ten days of the experiment.

The highest biogas yield at thermopfilic temperature range was achieved with maize variety NK PAKO, 611 NI kg VS^{-1}. The lowest biogas yield was in case of maize variety PR 34N43, 315 NI kg VS^{-1}. Biogas production in thermophilic temperature range from three maize varieties is shown in Table 3.

Biogas production of maize variety NK PAKO in norm litre per kg of volatile solids (NI (kg $VS)^{-1}$) during 5- week digestion in thermophilic temperature range is shown in Figure 7.

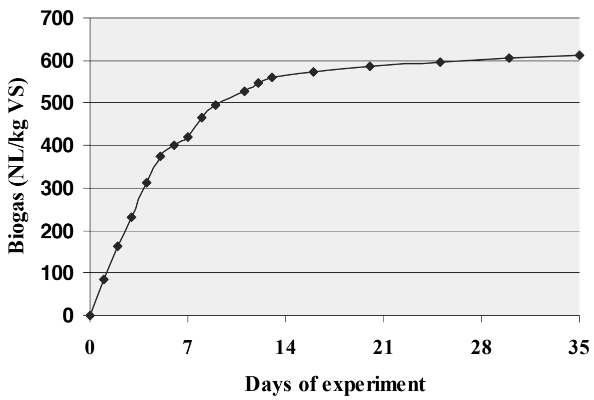

Fig. 7. Biogas production of maize variety NK PAKO during 5–week digestion

Biogas production of maize variety PR 34N43 in norm litre per kg of volatile solids (NI (kg $VS)^{-1}$) during 5- week digestion in thermophilic temperature range is shown in Figure 8.

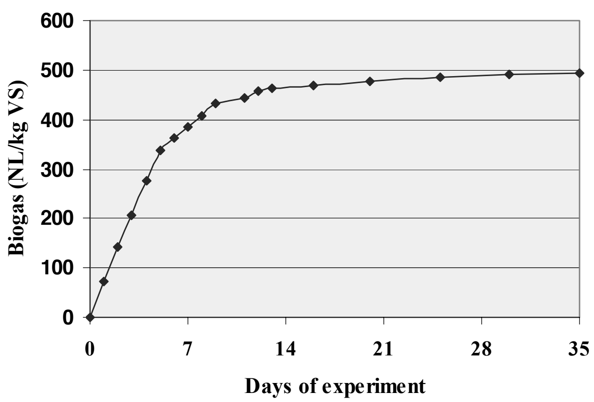

Fig. 8. Biogas production of maize variety PR 34N43 during 5–week digestion

Table 3.
Biogas production in thermophilic temperature range

Maize variety	Biogas production (Nl/kg VS)
NK PAKO	611
PR 34N43	494
RAXXIA	571

Biogas production of maize variety RAXXIA in norm litre per kg of volatile solids (NI (kg $VS)^{-1}$) during 5- week digestion in thermophilic temperature range is shown in Figure 9.

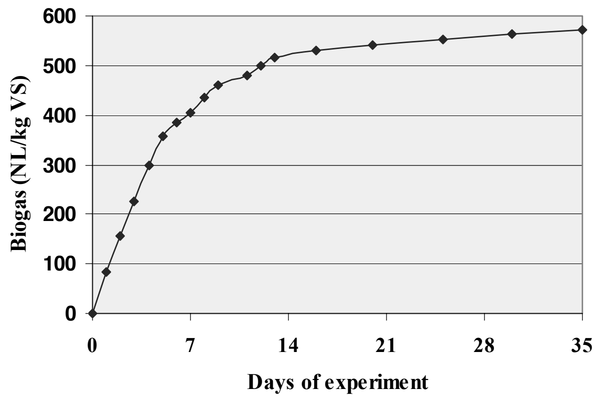

Fig. 9. Biogas production of maize variety RAXXIA during 5–week digestion

In the graphs it can be seen that the production of biogas in the first ten days increases the most rapidly, then remains constant and at the end is stable. With hybrid NK PAKO (FAO 440) for mesophilic and thermophilic temperature range the maximum biogas was produced during 35 days time period.

3.3. Comparison of biogas production in mesophilic and thermophilic temperature range

It is well known that there are three ranges of anaerobic degradation temperature: degradation at ambient temperature (psychrophilic range), mesophile degradation at 33-40 ° C and thermophilic degradation at 50-60 ° C. It is typical of the temperature ranges that at higher temperature decomposition take place quickly. Technically only the mesophilic and thermopfilic range is interesting, since at the ambient temperature the anaerobic degradation is extremely slow. Thermophilic anaerobic degradation is also up to 8 times faster and more efficient than mesophile degradation. The reason why it has never been used is the belief that it too much energy is used to maintain the temperature required. Thermophilic digestion is 4 times more intense, has higher VSS removal efficiency and yields more biogas.

Biogas production in the thermophilic temperature range with the hybrid NK PAKO is more intensive for 33% in comparison with mesophilic temperature range. In thermophilic range 202 Nl/kg VS more of biogas were produced. Figure 10 shows comparison of biogas production of maize variety NK PAKO during 5 – week digestion in mesophilic and thermophilic range. The biggest differences in the production of biogas occur in the first ten days of the experiment.

Biogas production in the thermophilic temperature range with the hybrid PR 34N43 is more intensive for 36% in comparison with mesophilic temperature range. In thermophilic range 179 Nl/kg VS more of biogas were produced. Figure 11 shows comparison of biogas production of maize variety PR 34N43 during 5 – week digestion in mesophilic and thermophilic range.

Biogas production in the thermophilic temperature range with the hybrid RAXXIA is more intensive for 38% in comparison with mesophilic temperature range. In thermophilic range 214 Nl/kg VS more of biogas were produced. Figure 12 shows comparison of biogas production of maize variety RAXXIA during 5 – week digestion in mesophilic and thermophilic range.

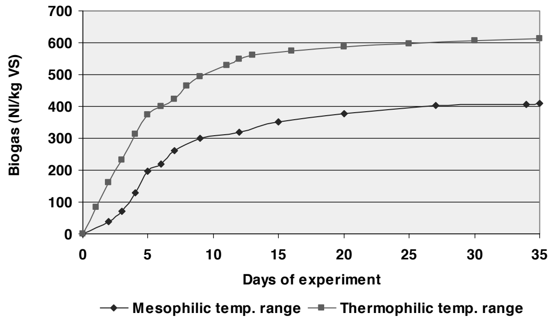

Fig. 10. Biogas production of maize variety NK PAKO during 5–week digestion

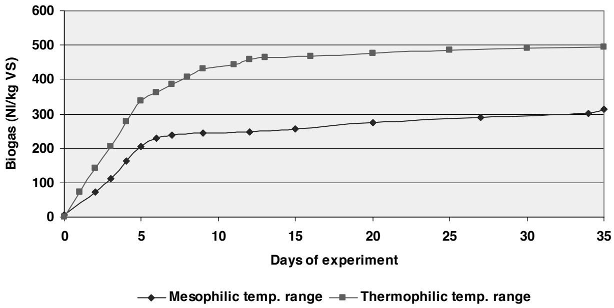

Fig. 11. Biogas production of maize variety PR 34N43 during 5–week digestion

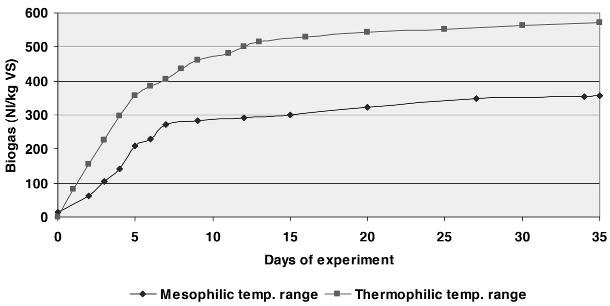

Fig. 12. Biogas production of maize variety RAXXIA during 5–week digestion

3.4. Biogas composition

Biogas composition (CH_4, CO_2 and O_2) was analysed 10 times in course of the 5 - week digestion with gas analyser GA 45.

Table 4 shows the biogas composition of three maize varieties in mesophilic and thermophilic temperature range. The average methane content ranged from 56,9% to 57,7% for mesophilic temperature range and 59,8% to 64,3% for thermophilic temperature range. The average content of CO_2 ranged from 32,5% to 34,8% for mesophilic temperature range and 59,8% to 61,7% for thermophilic temperature range during 5 – week digestion. The maximal average level of CO_2 was 34,8% for mesophilic temperature range and 40% for thermophilic temperature range. Oxygen content in the biogas was under 1%. That means that the digestion was anaerobic. The biggest differences in biogas composition occur in the first ten days of the digestion and then the gas content is more or less stable.

Figure 13 shows the comparison of average biogas composition gas by gas (methane, carbon dioxide and oxygen). Biogas quality produced in thermophilic temperature range is better than biogas quality produced in mesophilic temperature range. That is why more biomethane is produced in thermophilic temperature range. From the same substrate we can produce more biomethane by using thermophilic anaerobic digestion.

Table 4.
Biogas composition of three maize varieties

Maize variety	Mesophilic temperature range		Thermophilic temperature range	
NK PAKO	CH_4	57,7%	CH_4	59,9%
	CO_2	32,5%	CO_2	39,1%
	O_2	0,4%	O_2	0,5%
PR 34N43	CH_4	56,9%	CH_4	61,7%
	CO_2	34,6%	CO_2	38,0%
	O_2	0,2%	O_2	0,2%
RAXXIA	CH_4	57,7%	CH_4	59,8%
	CO_2	34,8%	CO_2	40%
	O_2	0,3%	O_2	0,2%

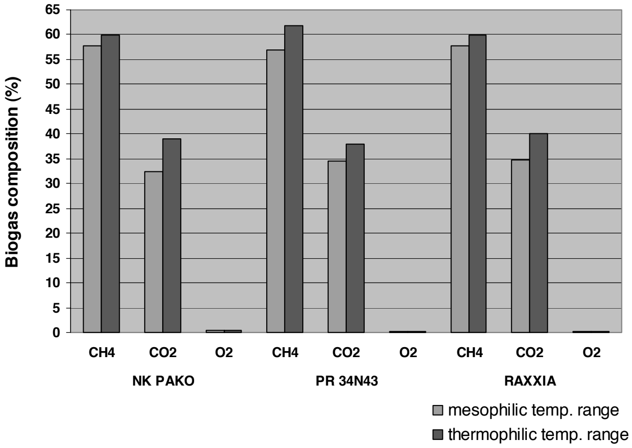

Fig. 13. Comparison of average biogas composition gas by gas

4. Conclusions

For achieving successful anaerobic digestion several physical and chemical factors must be considered. The most important physical factor is temperature. In anaerobic digestion there are generally two temperature ranges. Anaerobic sludge digestion can occur in the mesophilic range (35 °C), which is more usual, or in the thermophilic range (55 °C), which is less common. It is important that the temperature remains constant. Other physical factors, such as mixing, volatile solids loading and hydraulic retention time are also important.

This study investigated the performance of thermophilic anaerobic digestion prior to conventional mesophilic (methanogenic) anaerobic digestion. The aim was to observe biogas production and biogas quality (CH_4, CO_2 and O_2) in mesophilic and thermophilic anaerobic digestion.

The anaerobic digestion of three different maize varieties (NK PAKO (FAO 440), PR 34N43 (FAO 580) and RAXXIA (FAO 420)) in the mesophilic (35 °C) and thermophilic range (55 °C) was studied. Each mesophilic and thermophilic anaerobic digester has operated at constant temperature 37 °C and 55 °C for 35 days for each experiment.

Biogas yields ranged between 315 - 409 Nl kg VS^{-1} in mesophilic conditions and 494 – 611 Nl kg VS^{-1} in thermophilic conditions. The highest biogas yield was in case of NK PAKO (611 NI kg VS^{-1}) in thermophilic conditions. The lowest biogas yield was in case of PR34N43 (315 NI kg VS^{-1}) in mesophilic conditions.

The percentage of methane in biogas produced in thermophilic range is higher on the average for 2% in comparison with biogas produced in mesophilic range. That is why more biomethane is produced from the same substrate.

Thermophilic digestion is 4 times more intense, has higher VSS removal efficiency and yields more biogas. Thermophilic stabilization of energy plants at 55 ° C is truly economical, more biogas is produced. The only disadvantage of thermophilic stabilization is that more energy is used for heating fermenters.

Acknowledgements

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References

[1] A. Tiehm, K. Nickel, M. Zellhorn, U. Neis, Ultrasonic waste activated sludge disintegration for improving anaerobic stabilization, Water Research 35 (2001) 2003.2009.

[2] J.P. Delgenes, V. Penaud, R. Moletta, Pretreatments for enhancement of anaerobic digestion of solid waste, J. Mata-Alvarez Ed., Biomethanization of the Organic Fraction of Municipal Solid Wastes, Chapter 8. London: IWA Publishing, 2003, 201.

[3] P. Vindis, B. Mursec, M. Janzekovic, F. Cus, Processing of soybean meal into concentrates and testing for Genetically Modified Organism (GMO), Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 507-510.

[4] C. Bougrier, H. Carrere, J.P. Delgenes, Solubilisation of waste-activated sludge by ultrasonic treatment, Chemical Engineering 106 (2005) 163.

[5] J. Winter, U. Temper, Microbiology of the anaerobic wastewater treatment, Sewage Waste Recycle 38 (1987) 14-21.

[6] AG. Hashimoto, VH. Varel, YR. Chen, Ultimate methane yield from beef cattle manure: effect of temperature, constitute, antibiotics and manure age, Agriculture Waste 3 (1981) 241-256.

[7] B. Mursec, M. Janzekovic, F. Cus, U. Zuperl, Comparison of rollers after sowing of buckwheat, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 269-272.

[8] T. Amon, B. Amon, V. Kryvoruchko, W. Zollitsch, K. Mayer, L. Gruber, Biogas production from maize and dairy cattle manure—Influence of biomass composition on the methane yield, Agriculture, Ecosystems and Environment 118 (2007) 173-182.

[9] F. P. Gene, Fundamentals of anaerobic, Environmental Engineering 112 (1986) 867-920.

[10] E. J. Cook, Anaerobic sludge digestion: Manual of practice Alexandria VA: Water pollution control federation: Task force on Sludge stabilization, No. 16, 1986,

[11] DIN 38 414, 1985. Determination of digestion behavior ''sludge and sediments''. Beuth Verlag, Berlin (in German).

[12] B. Mursec, F. Cus, Integral model of selection of optimal cutting conditions from different databases of tool makers, Journal of Materials Processing Technology 133 (2003) 158-165.

[13] B. Mursec, F. Cus, J. Balic, Organization of tool supply and determination of cutting conditions, Journal of Materials Processing Technology 100 (2000) 241-249.

[14] P. Weiland, Production and energetic use of biogas from energy crops and wastes in Germany, Applied Biochemistry and Biotechnology 109 (2003) 263-274.

[15] K. Navickas, Biogas for farming, energy conversion and environment protection, International symposium, Biogas, technology and environment, University of Maribor, Faculty of Agriculture, 2007, 25-29.