ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LX 19 Number 6, 2012

EMPLOYMENT OF MAIZE SILAGE IN NON-LIQUID FERMENTATION FOR BIOGAS PRODUCTION

Z. Karafiát, T. Vítěz, K. Somerlíková, J. Gaduš, M. Haitl, T. Koutný

Received: September 14, 2012

Abstract

KARAFIÁT, Z., VÍTĚZ, T., SOMERLÍKOVÁ, K., GADUŠ, J., HAITL, M., KOUTNÝ, T.: *Employment of maize silage in non-liquid fermentation for biogas production.* Acta univ. agric. et silvic. Mendel. Brun., 2012, LX, No. 6, pp. 153–160

This paper deals with the optimization of the anaerobic fermentation process of maize silage using the non-liquid technology. The aim of the paper is to increase the knowledge necessary for more efficient running of biogas stations using batch technology of non- liquid fermentation. The preferable ratio of initial materials, fresh maize silage and maize silage after partial fermentation, was verified within this experiment. Dynamics of the process, especially the quantity and quality of produced biogas has been monitored during the experiment. All the experiments have been done in the batch-system fermentors of volume of 0.48 m^3 equipped with an independent and indirect circuit of water heating, the heat has been transferred to the material throught the steel wall of the fermentor. The material has been tested in the mesophilic conditions with the temperature of the 38 °C. The retention time of material in fermentors has been 27 days. The results of our experiments reveal the fact that the maize silage of lower mix ratio produced about 22.8 % more of biogas counted to one kilogram of dry matter than the maize silage of higher mix ratio.

non- liquid substrates, anaerobic fermentation, biogas, maize silage

Transformations of biogas offer a large scale of advantages in comparison with the other technologies using the renewable sources of energy. Biogas technologies were evaluated as the most power-efficient and ecologically rewarding technologies of energy production coming from renewable sources (Fehrenbach, 2008). One of the perspectives according to which technologies of biogas production can be distinguished is the content of dry matter (DM) in the processed material. Generally speaking, when the content of dry matter is up to 15% we talk about technology of liquid fermentation otherwise when the content of dry matter is higher we talk about non-liquid fermentation.

Due to the absence of complete information about the process of fermentation of non-liquid substrates, laboratories for research of non-liquid fermentation have been put into operation.

This project was implemented by FORTEX AGS Ltd. in cooperation with Mendel University in Brno. This paper deals with the use of maize silage in non-liquid fermentation technology. It is usually the discontinual technology with percolate spraying, without mechanical mixing of fermented material, which is used for fermentation of energy crops (Weiland, 2010). Silage making process of maize plants is a convenient method for maintaining energetic profit of cultivated plants (Vervaeren, 2010). At the present, maize silage is the most important material for biogas production, as individual substrate and also in combination with other plants or livestock manures. Compared with the use of particular materials in biogas stations in Germany we can simply find that the maize silage is used in 90 % of cases, so it is the most common used material (Weiland, 2003). The aim of our research was to determine the best initial mix ratio of maize silage entering the biogas station. Literary sources say that the best initial mix ratio is in proportion of 70 % of maize silage partly anaerobically processed, plus 30 % of fresh material (Kusch, 2005). The influence of these two main proportions as well as the effect on the biogas production has been verified in this paper.

MATERIAL AND METHODS

Maize silage prepared from the plants including the ears, has been used for this experiment. A fresh amount of maize silage has been used for every single experiment. The difference of mix ratio of fresh material and material after fermentation and their influence on the process of the fermentation has been determined within the experiment. Ten laboratory experiments with different initial amount of fresh maize silage have been done. The time period for which the material has been left in the fermentor was set to 27 days. The five different tests within the first experiment, concerning lower mix-ratio, have been done. Maximum of 33% of fresh maize silage has been added to the already fermented material. From the total weight of input material, which ranged between 153–167 kg, the addition of fresh maize silage has been 51–55 kg. In the second experiment the five different tests, concerning higher mix ratio, have been done. Between 44–57% of fresh maize silage has been added to the material after fermentation. The total weight of input material ranged between 137–166 kg and the addition of fresh maize silage has been 63–95 kg.

All the experiments have been run in six steel laboratory batch fermentors of the volume of 0.48 m^3, equipped by hot water circuit (Fig. 1). Heating of the material in the fermentors has been done through the wall between the fermented material and hot water circuit. Anaerobic decomposition has been run in the mesophilic conditions. The temperature in the fermentors has been 38 °C ± 2 °C, during the fermentation the material has been sprayed by processing liquid – percolate. The percolate serves as a source of methanogenic microorganisms. The developed biogas has been collected into gas sacs, for later analysis. The process has been discontinual, so after 27 days a part of the original material has been replaced by a new amout of the material in choosed mix ratio. The initial material dry matter content ranged from 23% to 30%. Collections of data were obtained during the daily measuring showing, where the temperature of the material, pH of percolate, the temperature of percolate, the pressure in the fermentor, quantity of the developed biogas and its quality (CH_4, CO_2, H_2S, O_2) have been measured. Furthemore, the dry matter content (60 °C and 105 °C), loss on ignition (595 °C), the content of fatty acids (acetic acid, butyric acid, lactic acid etc.), ammonia content, suspended solids, have been measured as well. Mobile gas analyser Biogas (Geotech, United Kingdom) has been used for the biogas analysis. The quantity of developed biogas has been measured by gas flow meter Premagas BK G4 (Premagas, Czech Republic).

Biogass production has been related to one kilogram of organic dry matter of tested samples and subsequently calculated by Equation of state (1) regarding standard conditions (pressure 101.325 kPa, temperature 273.15 K).

$$p \cdot V = n \cdot R \cdot T \qquad [-] \qquad (1)$$

The results of all given measurements have been statistically evaluated by Statistica programme. Homogenity in differences of values has been tested by F-test and further testing using bivalent t-tests has been based on this results. The data has been tested on distantness by Grubbs's test.

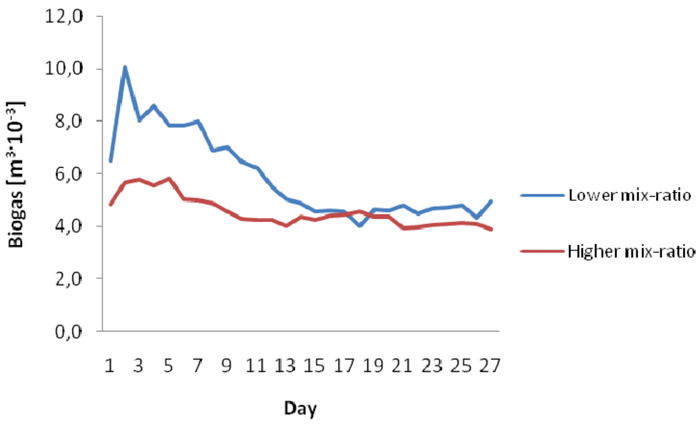
1: *Laboratory fermentors (Karafiát)*

RESULTS AND DISCUSSION

There have been found the lower biogas and methan production for maize silage with higher mix ratio. The average biogas production for maize silage with higher mix ratio has been about $122.6 \cdot 10^{-3}\,m^3$ related to the one kilogram of organic dry matter. Maize silage with lower mix ratio has produced $158.8 \cdot 10^{-3}\,m^3$ of biogas related to the one kilogram of organic dry matter (Tab. I). Other authors presents their results of biogas production from maize silage in non-liquid fermentation in the range of $455 \cdot 10^{-3}\,m^3$–$603 \cdot 10^{-3}\,m^3$ related to the one kilogram of organic dry matter (Schittenhelm, 2008). The production of the methane from maize silage with lower mix ratio has been about $74.9 \cdot 10^{-3}\,m^3$ related to the one kilogram of organic dry matter and the production of methane from maize silage with higher mix ratio has been about $60.6 \cdot 10^{-3}\,m^3$ related to the one kilogram of organic dry matter. The other authors present their results of methane production from the liquid fermentation in the range of $398 \cdot 10^{-3}\,m^3$ of methane related to the one kilogram of organic dry matter (Amon, 2007), $370 \cdot 10^{-3}\,m^3$–$400 \cdot 10^{-3}\,m^3$ of methane related to the one kilogram of organic dry matter (Straka, 2007) and $282 \cdot 10^{-3}\,m^3$–$419 \cdot 10^{-3}\,m^3$ of methane related to the one kilogram of organic dry matter (Schittenhelm, 2008).

I: *Comparision of biogas and methane production related to the one kilogram of organic dry matter, for maize silage with lower and higher mix ratio*

	Biogas production	Methane production
	[$m^3 \cdot 10^{-3}$]	[$m^3 \cdot 10^{-3}$]
Test 1	160.9	80.1
Test 2	157.6	76.9
Test 3	164.4	74.9
Test 4	153.2	70.3
Test 5	157.7	72.1
Experiment 1 MEAN	**158.8**	**74.9**
Test 1	113.9	54.7
Test 2	111.8	56.7
Test 3	131.6	65.5
Test 4	118.7	59.0
Test 5	136.8	68.7
Experiment 2 MEAN	**122.6**	**60.6**



2: *The average values of daily production of biogas related to the one kilogram of organic dry matter, for maize silage with lower and higher mix ratio*

II: *Bivalent t-test of methane production from maize silage with lower and higher mix ratio*

	Val.	Average	Determinant margin for error	Determinant error
Difference	27	1.3333	1.1606	0.2234

t-statistics = 5.9697
Level of leeway = 26.0000
Bilateral probability = 0.0000

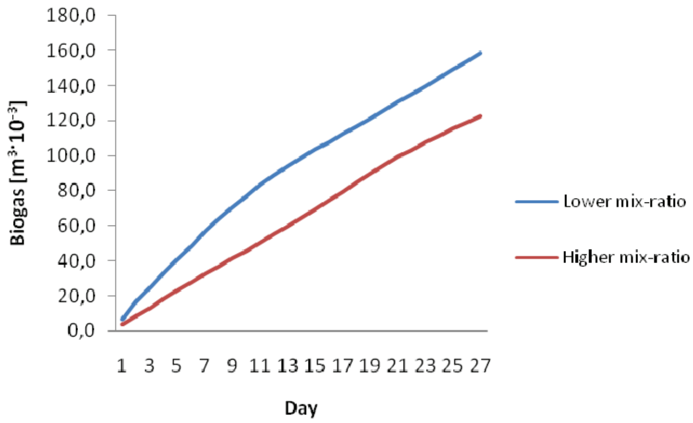
Biogas production

After the initiation of the anaerobic fermentation process, maize silage with lower mix ratio has had more intensive production of biogas. The highest production of biogas has been reached the second day of the process and it has been about $10.1 \cdot 10^{-3}$ m³. Subsequently, the production of biogas has been slowly decreasing until the thirteenth day of our experiment the production of biogas has ranged between $4 \cdot 10^{-3}$ m³–$5 \cdot 10^{-3}$ m³. The results of fermentation of the maize silage with higher mix ratio were oscilated between $3.9 \cdot 10^{-3}$ m³–$5.8 \cdot 10^{-3}$ m³ and have been uniform during the whole period of our experiment. The highest production of biogas has ben reached the third and the fifth day of our experiment (Fig. 2).

The results of bivalent t-test reveal statistically important difference between the daily production of biogas from maize silage with lower and higher mix ratio (Tab. II).

Cumulative production of biogas

More intensive biogas production from the material with lower mix ratio has been achieved especially at the beginning of the experiment. Production of the biogas at the end of the experiment has been $158.8 \cdot 10^{-3}$ m³. The experiment with the material with higher mix ratio shows that

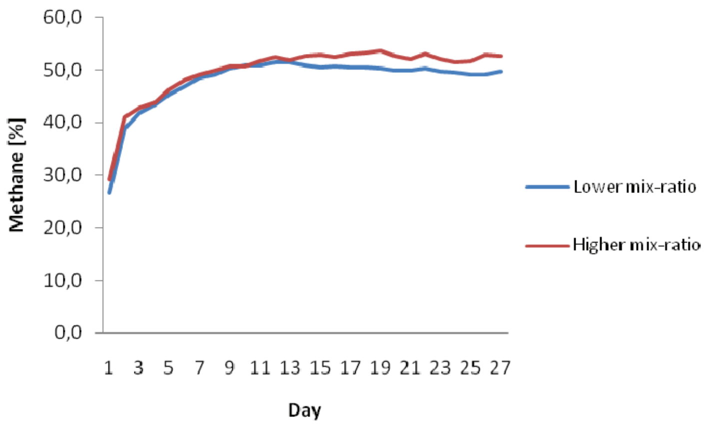


3: *The average values of cumulative biogas production per one kilogram of the organic dry matter for the maize silage with lower and higher mix ratio*

III: *Bivalent t-test of cumulative production of methane from maize silage with lower and higher mix ratio*

	Val.	Average	Determinant margin for error	Determinant error
Difference	27	27.7444	9.1028	1.7518

t-statistics = 15.8374
Level of leeway = 26.0000
Bilateral probability = 0.0000



4: *The methane content in the biogas generated from maize silage with lower and higher mix ratio.*

IV: *Bivalent t-test of methane content from maize silage with lower and higher mix ratio*

	Val.	Average	Determinant margin for error	Determinant error
Difference	27	–1.7593	1.0591	1.2038

t-statistics = –8.6311
Level of leeway = 26.0000
Bilateral probability = 0.0000

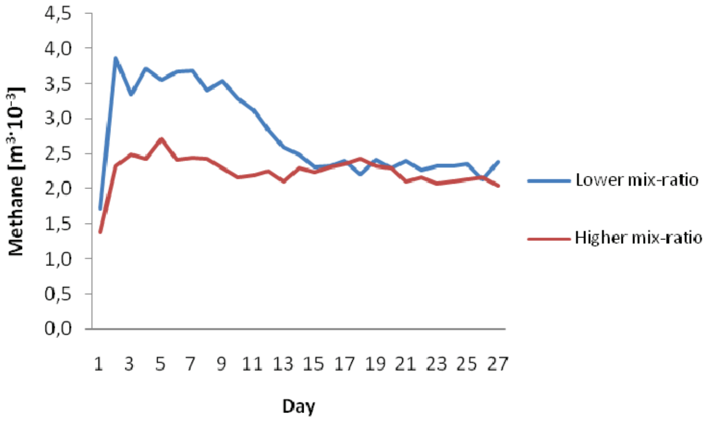
the production of biogas has been lower but stable during the whole experiment and it has been $122.6 \cdot 10^{-3}$ m³ of biogas at the end of the experiment (Fig. 3).

The result of bivalent t-test shows statistically highly important difference of cumulative biogas production from maize silage with lower and higher mix ratio (Tab. III).

Content of methane

The content of methane has been uniform until the thirteenth day of the experiment. The highest content of the methan in biogas has been achieved the twelfth day of the experiment and it has been 51.4% for the maize silage with lower mix ratio. Afterwards, the content of methane has been gradually decreasing. The average content of the methane in biogas has been about 50.1% from the seventh day of the experiment and the average content of the methane in biogas from maize silage with higher mix ratio has been 52% from the seventh day of the experiment (Fig. 4). The highest value of the methane content in generated biogas from maize silage with higher mix ratio (53.6%) have been measured the nineteenth day of the experiment. Liebneiner (2010), presents the methane content of 53.4% in biogas during processing of maize silage due to non- liquid fermentation. Oslaj (2010), on the other hand, presents the methane content in the range of 55.1–58.2% in biogas during processing of maize silage due to liquid fermentation.

The result of bivalent t-test shows statistically highly important difference in the content of biogas generated from maize silage with lower and higher mix ratio (Tab. IV).

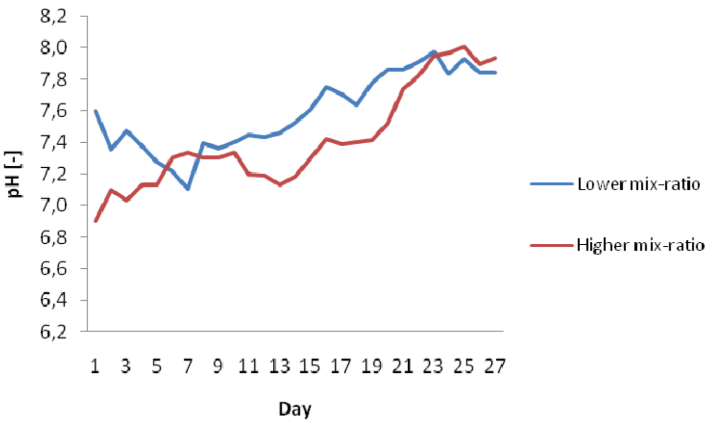


5: *Production of methane related to the one kilogram of dry matter made from maize silage with lower and higher mix ratio*

V: *Bivalent t-test of production of methane from maize silage with lower and higher mix ratio*

	Val.	Average	Determinant margin for error	Determinant error
Difference	27	0.5333	0.5226	0.1006

t-statistics = 5.3032
Level of leeway = 26.0000
Bilateral probability = 0.0000



6: *Development of pH values for maize silage with lower and higher mix ratio*

VI: *Bivalent t-test of pH values for maize silage with lower and higher mix ratio*

	Val.	Average	Determinant margin for error	Determinant error
Difference	27	0.1815	0.2237	0.0430

t-statistics = 4.2160
Levels of leeway = 26.0000
Bilateral probability = 0.0003

The amount of generated methane

The highest production of methane within the experiment 1 was reached from day two to day seven with a maximum value of $3.9 \cdot 10^{-3}\,m^3$ of methane, from seventh day the amount of generated methan has been gradually decreasing and it has been stabilized on the final value $2.3 \cdot 10^{-3}\,m^3$ of methane production. The overall production of methane has been $74.9 \cdot 10^{-3}\,m^3$ during the experiment. The average daily production of the methane has been $2.2 \cdot 10^{-3}\,m^3$, with the maximum of $2.7 \cdot 10^{-3}\,m^3$ during the experiment 2 and the maximum value of generated methane has been reached the fifth day of the experiment. The overall production of methane of the whole experiment has been $60.0 \cdot 10^{-3}\,m^3$ (Fig. 5).

The result of bivalent t-test shows statistically highly important difference in the production of biogas from maize silage with lower and higher mix ratio (Tab. V).

pH values

The decrease of pH to 7 is apparently considered at the beginning of the both experiments. Afterwards it has been observed that pH values were slowly increasing up to pH 8 (Fig. 6).

6: Development of pH values for maize silage with lower and higher mix ratio

The result of bivalent t-test shows that there has been determined a statistically significant difference in pH values for maize silage with lower and higher mix ratio (Tab. VI).

SUMMARY

This paper deals with evaluation of experiments with fermentation of maize silage with different mix ratio of fresh material. All the experiments have been run in the laboratory batch fermentors designed for fermentation of non-liquid substrates. All data determined during the experiments have been used as basis for further use and material production for biogas station. The experiments proved higher production of biogas when the content of fresh material is lower. Higher mix ratio influenced the content of methane in biogas only insignificantly. The results confirmed the importance of keeping the right proportion of fresh material and already fermented material. The most essential thing for the best biogas production is a proper mixing of fresh material with already fermented material. We have got valuable and unique information due to our laboratory experiments. These informations can be used by operators of biogas stations for optimization and economial effectiveness of running biogas stations and processing of non- liquid substrates.

Acknowledgement

The project was co-financed from „The National Programme of Reasearch II" – Permanent prosperity, the project number 2A-3TP/010, The Operating Programme for Business and Innovation- EKO-Energy, the project number 3.1 EEDOZE/140, by the Sixth Framework Programme of the European Community for research, technological development and demonstration activities (2007–2017), No. 7AMB12SK076 Production of biogas from non-traditional biodegradable materials by project CZ.1.02/5.1.00/10.06433 Acquisition of Instrumentation for BAT Centre at MZLU in Brno for Categories of Food Processing Activities and Categories of Facilities for Disposal or Destruction of Animal Bodies and Animal Waste.

REFERENCES

AMON, T., AMON, B., KRYVORUCHKO, V., ZOLLITSCH, W., MAYER, K., GRUBER, L., 2007: *Biogas production from maize and dairy cattle manure- Influence of ass composition on the maize yield*, Agriculture, Ecosystems & Environment, 118: 173–182. ISSN 0167-8809.

KUSCH, S., OECHSNER, H., 2005: *Vergärung landwirtschaftlicher Substrate in diskontinuierlichen Feststofffermentern*. Landtechnik, 4: 214–215. ISSN 0023-8082.

OSLAJ, M., MURSEC, B., VINDIS, P., 2010: *Biogas production from maize hybrids*, Biomass Bioenergy, 34: 1538–1545. ISSN 0961-9534.

SCHITTENHELM, S., 2008: *Chemical composition and methane yield of maize hybrids with contrasting maturity,* European Journal of Agronomy, 29 (2–3): 72–79. ISSN 1161-0301 http://www.sciencedirect.com/science/article/pii/S1161030108000427#bib30.

STRAKA, F., DĚDEK, J., DOHANYOS, M., KUNČAROVÁ, M., MALIJEVSKÝ, A., NOVÁK, P. J., ZÁBRANSKÁ, J., 2007: *Bioplyn*. 2. vyd. Praha: GAS s. r. o., 706 s. ISBN 80-7328-090-6.

WEILAND, P., 2010: *Biogas production: current state and perspectives*, Appl. Microbiol. Biotechnol., 85: 849–860. ISSN 1432-0614.

VERVAEREN, H., HOSTYN, K., GHEKIERE, G., WILLEMS, B., 2010: Biological ensilage additives as pretreatment for maize to increase the biogas production, Renewable Energy, 35: 2089–2093. ISSN 2090-4541.

WEILAND, P., 2003: Production and energetics use of biogas from energy crops in Wales and Germany. Applied Biochem. Biotechnol. 109 (1–3) 263–274. ISSN 1559-0291.

Address

Ing. Zbyšek Karafiát, Ing. Tomáš Vítěz, Ph.D., Ing. Martin Haitl, Ing. Tomáš Koutný, Ústav zemědělské, potravinářské a environmentální techniky, Ing. Kristina Somerlíková, Ph.D., Ústav demografie a aplikované statistiky, Mendelova univerzita v Brně, Zemědělská 1, 613 00 Brno, Česká republika, prof. Ing. Ján Gaduš, PhD., Slovenská zemědělská univerzita v Nitře, Katedra konstruování strojů, Trieda A. Hlinku 2, 949 76, Nitra, Slovenská republika, e-mail: xkarafi0@node.mendelu.cz