UDC 65.011.46:621

SILAGE FROM THE STANDARD RYE AS SUBSTRATE FOR THE PRODUCTION OF AGRICULTURAL BIOGAS

J. BOHDZIEWICZ, Ph.D., D. Sc. (Eng.), Professor
Silesian University of Technology in Gliwice, Poland
J. CEBULA, Ph.D., D. Sc. (Eng.), Associate Professor
The University of Bielsko-Biała, Poland
K. PIOTROWSKI, Ph.D., D. Sc. (Eng.), Assistant Professor
Silesian University of Technology in Gliwice, Poland
P. SAKIEWICZ, Ph.D (Eng.)
Silesian University of Technology in Gliwice, Poland

…

Abstract. *Necessity of electricity generation together with climate protection make us do reaching out for renewable energy resources. Year in, year out the demand for renewable biofuels grows, which will be able to replace the presently used fuel products based on nonrenewable natural oil and coal. The possibilities and prospects of industrial-scale utilization of silage made of standard rye (Secale cereale L.) for the biogas production are presented. It is important technological issue, especially in these countries, where high potential and agricultural tradition of this cereal type cultivation exists. The measurement results concerning the methane fermentation process course are presented and discussed. Analysis results concerning selected elements contents in silage are also provided.*

Key words: ***biogas, biomethane, secale cereale L., standard rye, silage***

Introduction. In the nearest future making use of soil will be connected not only with food production, but also with energy generation. It will cause demand for agricultural biomass to happen. It results from emission of greenhouse gases into the atmosphere, which in case of direct biomass burning or/and its conversion into fuel(s) provides closed CO_2 cycle [1]. Demand for food will also induce the growth of animal production [2]. Intensive animal breeding, especially connected with high breeding density, as it is usually observed in animal breeding farms, is closely connected with generation of significant amounts of feaces. Modern pig fatten farms are the most often run in a bedding-free system, thus the feaces are removed from the system in a form of liquid manure. However, it represents hazard for natural environment, including inland waters, soils and air. Essential effect on the biosphere is exerted by nitrogen, emitted in a form of ammonia. It is estimated, that the amount of ammonia emitted by the pigs reaches even 5,1 kg NH_3/(animal$\times$year). Ammonia emission starts as early as in the farm buildings, continues during storage, transport and during inappropriate distribution of

liquid manure on the agricultural fields. The nitrogen compounds emitted from the farms contaminate air, ground and surface waters nearby the farms and fields fertilized with the use of liquid manure. High doses of such fertilizer type over the agricultural fields can lead to permanent anaerobiose, thus in result inhibition of biological life in the soil environment. Atmospheric air in the vicinity of the farms is contaminated with methane, carbon dioxide, carbon monoxide, ammonia, mercaptanes, aldehydes, amines, hydrogen sulphide and other compounds, which at their high concentrations are poisons. Since these are the compounds characterized by very low smell threshold (low concentration), thus even small amounts of these emitted are smell detectable and make deterioration of the air quality in result of unpleasant, characteristic smelt. Thus new technologies of these feaces utilization integrated with simultaneous energy production are sought-after [3,5,6,7].

Co-fermentation of green biomass with liquid manure offers splendid conditions both for troublesome liquid manure utilization and for renewable energy production. It represents one from the experimentally verified, economically justified methods. The process is based on anaerobic decomposition of easily decomposable, macromolecular organic compounds into simpler chemical species, whereas sparingly decomposable compounds into the stable ones. Present animal breeding farms should be modernized or replaced with modern technological plans. It will make reduction of animal breeding inconvenience for natural environment and biosphere possible. Moreover, according to the idea of practical utilization of renewable energy sources the biogas production technologies are worth recommending. For the research tests e.g. fermentation in nylon sacks is introduced [4]. Industrial scale solutions make use of not only concrete-based reactor constructions (Fig. 6), but also some constructions made with sheets of enamel metal (Fig. 5).

Fig. 1. Standard rye ready for silage production (photo J. Cebula)

Development of the agricultural wastes conversion methods together with energetic plants especially designed for energy production is a chance for the development of many knowledge domains like: organization of biogas

production, economy, ecology, chemical/biochemical technology. It also favors unification of effort towards construction of new, local agricultural biogas plants, biomass production specially intended for biogas synthesis, modern directions of agricultural biogas applications in the transport, etc. All over the world one observes increasing activities oriented for pretreatment of biogas for the use in the fuel cells or as the fuel for internal combustion engines and for co-generation systems.

The main aim of the presented research was determination of the possibilities of the standard rye silage utilization for the agricultural biogas production. Determination of the silage decomposition course during the methane fermentation process is of primary interest. The laboratory tests were also oriented for realistic simulation of the anaerobic fermentation process in a biogas plant.

Experiments. One of the substrates convenient for biogas production may be silage made of standard rye. The standard rye was harvested during ripen season what makes sowing and harvest from the same field crop cultivated between main crops, which can also be used in silage production in the same vegetation season, possible. Farmers are interested in gaining large biomass crops from 1 ha. The plant type of the known requirements, destined for silage, is thus standard rye. Fig. 1 presents this plant just before harvest.

Methodology of the laboratory scale tests, as well as analytical description of the processes observed were taken from the German norm DIN 38414-8 determining the research methods for water, wastewater and wastewater sludge (sediments) analysis. The norm includes descriptions of the biological-chemical methods for research and tests in susceptibility to anaerobic decomposition of the sludges and wastewaters of high content of organic substances. Diversification of biogas yields from the organic substances conversion was roughly assumed as the conventional measure and quantification of this susceptibility. Measurement stand and equipment, as well as the experimental results analysis methods are presented in detail in [8]. In Fig. 2 an sample of silage used for the tests and analyses is presented.

Fig. 2. Sample of silage made of standard rye used for experiment (photo J. Cebula)

In industrial scale silage from standard rye is produced with the use of heavy equipment (Fig. 3). Part of silage derived from the previous year crops is also visible.

Fig. 3. Production of silage from standard rye for the biogas plant and animals feeding (photo J. Cebula)

For the transportation of silage from silos and chambers made directly on the fields the self-unloading trailers are in the common use (Fig. 4).

Fig. 4. The self-unloading trailer used for transportation of silage in a biogas plant (photo J. Cebula)

New domain of knowledge and biochemical industry - energy production based on biogas synthesis – makes use of the most modern technical solutions. In some countries metal-made reactors are used (Fig. 5), whereas in others reinforced concrete constructions are in practical use (Fig. 6).

Fig. 5. Fermenters made of enamel metal sheets (photo J. Cebula)

Fig. 6. Fermenters made of reinforced concrete and insulated with polystyrene foam (photo J. Cebula)

We determined of content elements important from a points of view of fertilizing plants (Fig. 7, 8).

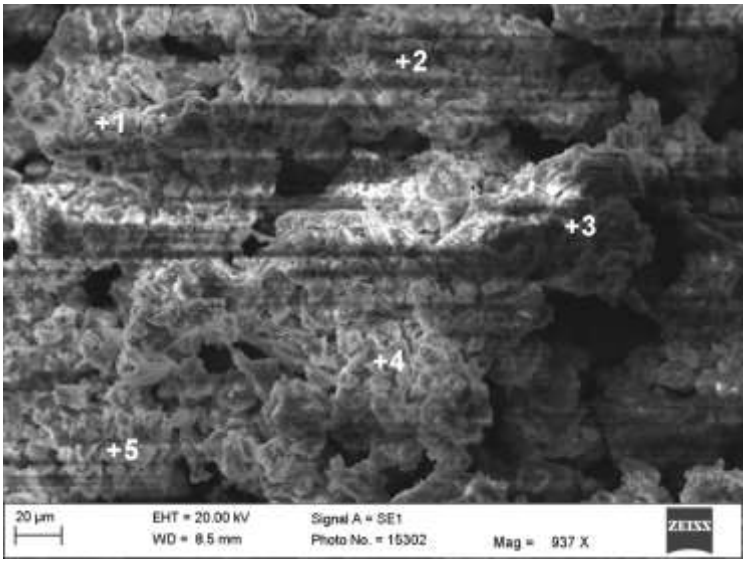

Fig. 7. Scanning electron microscope image of burn to ashes rye

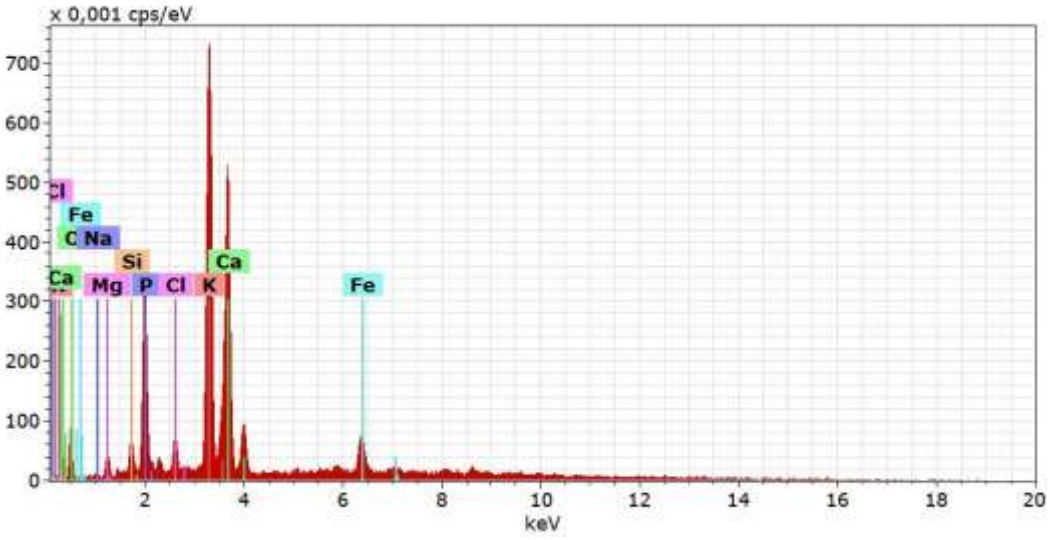

Fig. 8. Analytical EDS test results concerning elements content in a sample of burn to ashes silage made of standard rye

1. Analytical EDS test results concerning elements content in a sample of mineralized silage made of standard rye

Element	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
Oxygen	32,568	22,790	12,281	32,287	23,820	24,749
Potassium	29,668	28,824	56,075	40,195	49,127	40,777
Calcium	11,604	27,101	4,308	4,379	3,246	10,127
Phosphorus	5,603	7,153	3,406	7,311	5,157	5,726
Chloride	5,137	5,970	10,807	1,850	5,275	5,807
Carbon	5,280	2,022	0,420	2,669	2,060	2,490
Silica	4,094	1,947	8,149	7,402	7,763	5,871
Magnesium	2,914	1,476	1,998	1,817	1,911	2,023
Natrium	1,292	0,551	0,444	0,456	0,621	0,672
Sulphide	1,241	1,245	1,108	1,093	0,350	1,007
Iron	0,596	0,885	0,998	0,539	0,662	0,736

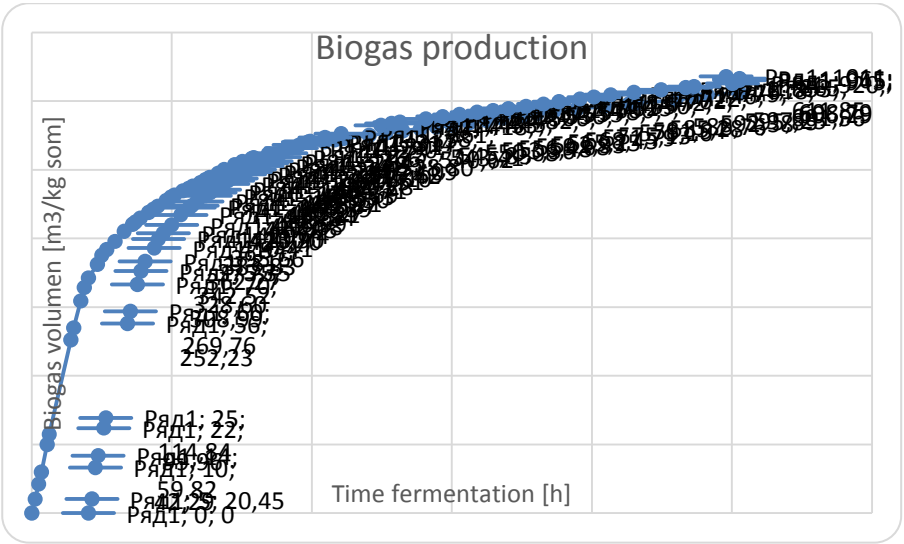

Fig. 9. Batch biogas production course based on silage substrate made of standard rye – process kinetics

The inoculum source was cattle liquid manure derived from the fermentation chamber of the agricultural biogas plant. The guidelines for inoculum preparation technique and its details are available in a German norm DIN 38414-8 determining the research methods recommended for water, wastewaters, wastewater sediments analysis in respect to determination of their potential for anaerobic decomposition.

Results. Scanning electron microscope image of the silage sample is presented in Fig. 7. In the image one can notice highly porous, layered structure, suggesting necessity of liquid penetration of the particles interior before leaching and diffusional transport of the dissolved substance to the bulk solution. The possible diffusional mass transport resistances may be regarded as the kinetic limiting factor, since only leached dissolved organic substance can be further biochemically processed towards biogas synthesis. Moreover, in selected localizations of the sample the EDS measurements were done. Test results concerning elements content in a sample are presented in Fig. 8 and Table 1. From the table it results, that it can be useful as fertilizer.

In Fig. 9 the research results concerning the intrinsic ability for biogas production of standard rye silage as a function of the batch process time are presented. The resulting time can be also interpreted as the necessary hydraulic retention time (HRT) of the substrate in a bioreactor working volume. Analyzing the plot one can conclude, that the highest biomass production rate is observed up to 100 h only, with corresponding total biogas volume of ca. 375 m^3/kg som. After this time anaerobic process rate gradually decreases. Practically after 400 h of the batch process course the increments of produced biogas volume are rather small. The mentioned finding can be the basis for methane fermentation process design and optimization and determines thus the optimum time for the given batch biomass conversion. Longer residence time of silage in working volume of the bioreactor is not recommended economically since productivity decreases significantly.

Conclusions

Based on the laboratory test results one can conclude, that silage made of standard rye is a good substrate for biogas production. Calorific value of the biogas depends on the methane content which under the experimental results reached ca. 54%. Assuming average harvest of standard rye destined for silage production, one can obtain about 9000 m^3 of biogas from 1 ha.

References

1. Poppa, A., Calvin, K., Shinichiro Fujimori, Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B. L., Dietrich J. P., Doelmann, J. C., Gusti, M., Hasegawa T., Page Kyle, Obersteiner, M., Tabeau, A., Kiyoshi Takahashi, Valin, H., Waldhoff, S., Weindlj, I., Wise, M., Kriegler, E., Lotze-Campen, H., Fricko, O., Keywan Riahi, Detlef P. van Vuuren. Land-use futures in the shared socio-economic pathways, Global Environmental Change 42 (2017) 331–345

2. Notarnicola, B., Tassielli, G., Renzulli, P. A., Castellani, V., S. Sala. Environmental impacts of food consumption in Europe. Journal of Cleaner Production 140 (2017) 753-765

3. Rigel, A., Rivero, G., Daim, T. Technology roadmap: Cattle farming sustainability in Germany. Journal of Cleaner Production 142 (2017) 4310-4326
4. Negri, M., Bacenetti, J., Fiala, M., Bocchi, S. Evaluation of anaerobic degradation, biogas and digestate production of cereal silages using nylon-bags. Bioresource Technology 209 (2016) 40–49
5. Riggio, S. , Torrijos, M., G. Vives, Esposito, G., E. D. van Hullebusch, Steyer, J. P., Escudié, R. Leachate flush strategies for managing volatile fatty acids accumulation in leach-bed reactors. Bioresource Technology 232 (2017) 93–102
6. Rodriguez, C., Alaswad, A., Benyounis, K. Y., Olabi, A. G.. Pretreatment techniques used in biogas production from grass. Renewable and Sustainable Energy Reviews 68 (2017) 1193–1204
7. Senghor, A., Dioh, R. M. N., Müller, C., Youm, I. Cereal crops for biogas production: A review of possible impact of elevated CO_2. Renewable and Sustainable Energy Reviews 71 (2017) 548–554
8. Bohdziewicz, J., Piotrowski, K., Sakiewicz, P., Cebula, J. Production of biogas from waste animal fats. Naukovij Visnik Nacional'nogo Universitetu Bioresursiv i Prirodokoristuvanna Ukraini ISSN 2222-8594

СИЛОС ІЗ ЖИТА ЯК СУБСТРАТ ДЛЯ ВИРОБНИЦТВА БІОГАЗУ

Я. Бохджієвіч, Я. Цебуля, К. Піотровський, П. Сакіевіч

Анотація. *Необхідність виробництва електроенергії в поєднанні із захистом навколишнього середовища змушує робити наголос на використання поновлюваних джерел енергії. З року в рік зростає попит на поновлюване біопаливо, яке зможе замінити застосовувані нині паливні продукти на основі невідновлюваних природних олив і вугілля.*

Представлені можливості і перспективи промислового використання силосу із жита (Secale cereale L.) для виробництва біогазу. Це важливе технологічне питання, особливо в тих країнах, де є високі потенційні і сільськогосподарські традиції вирощування зернових культур. Наведені та обговорені результати досліджень, що стосуються процесу метанового бродіння. Також наводяться результати аналізу вмісту окремих елементів в силосі.

Ключові слова: ***біогаз, біометан, secale cereale L., жито, силос***

СИЛОС ИЗ РЖИ КАК СУБСТРАТ ДЛЯ ПРОИЗВОДСТВА БИОГАЗА

Я. Бохджиевич, Я. Цебуля, К. Пиотровский, П. Сакиевич

Аннотация. *Необходимость производства электроэнергии в сочетании с защитой окружающей среды заставляет делать упор на использование возобновляемых источников энергии. Из года в год растет спрос на возобновляемое биотопливо, которое сможет заменить используемые в настоящее время топливные продукты, на основе невозобновляемых природных масел и угля.*

Представлены возможности и перспективы промышленного использования силоса из ржи (Secale cereale L.) для производства биогаза. Это важный технологический вопрос, особенно в тех странах, где имеются высокие потенциальные и сельскохозяйственные традиции

выращивания зерновых культур. Приведены и обсуждены результаты исследований, касающихся процесса метанового брожения. Также приводятся результаты анализа содержания отдельных элементов в силосе.

Ключевые слова: ***биогаз, биометан, secale cereale L., рожь, силос***

УДК 004.896

ОБ'ЄКТНО-ОРІЄНТОВАНИЙ МЕХАНІЗМ ІНВЕСТИЦІЙНО-ФІНАНСОВОЇ ОЦІНКИ ВПРОВАДЖЕННЯ ЕЛЕКТРОТЕХНОЛОГІЙ В СФЕРІ РАЦІОНАЛЬНОГО ВОДОКОРИСТУВАННЯ

В. М. ШТЕПА, кандидат технічних наук, доцент
С. П. ВЕРТАЙ, кандидат економічних наук, доцент
Є. І. САСЄВІЧ, аспірант*
П. І. БУРІК, студент магістратури*
Поліський державний університет,
м. Пінськ, Республіка Білорусь
E-mail: *shns1981@gmail.com*

Анотація. *У статті розглянуто механізм фінансування інновацій в області екології та природокористування. Запропоновано варіанти взаємодії розробника та користувача технології з урахуванням залучення фінансування для впровадження розробки в виробничий процес. Розрахунковим шляхом встановлено доцільність реалізації замкнутих циклів водопостачання – на основі показників використання водних ресурсів та індексу рентабельності. Оцінено критерії вибору та перспективності фінансування інноваційних розробок в сфері систем очистки стічних вод промислових об'єктів; запропоновано методику розрахунку об'ємів інвестицій в природоохоронні заходи, куди включено і критерій енергоефективності функціонування електротехнологічного обладнання водоочистки, як першочерговий показник.*

Ключові слова: ***технологія, інновація, природокористування, водоочистка, оборотне водопостачання, енергоефективність, рентабельність***

Актуальність. Актуальність широкого впровадження природоохоронних інноваційних технологій активно обговорюється в науково-практичних спільнотах (гайдарівський форум 2016, Міжнародний форум в Давосі). Однак, створення нових технологій в області екології та

* Науковий керівник – кандидат економічних наук, доцент С. П. Вертай