ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LIX 42 Number 6, 2011

MONITORING OF DRY ANAEROBIC FERMENTATION IN EXPERIMENTAL FACILITY WITH USE OF BIOFILM REACTOR

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Received: June 20, 2011

Abstract

ŠINKORA, M., HAVLÍČEK, M.: *Monitoring of dry anaerobic fermentation in experimental facility with use of biofilm reactor.* Acta univ. agric. et silvic. Mendel. Brun., 2011, LIX, No. 6, pp. 343–354

Anaerobic fermentation is a process in which almost any organic mass may be transformed into an energetically rich biogas and a fermentation residue. Only strictly anaerobic microorganisms enter into the process; thus the process may take place only in a hermetically sealed environment. With regard to the world wide situation, where the increase in the proportion of energy from sustainable sources is in demand, anaerobic fermentation offers the possibility of transforming farm waste, farm products and municipality waste of biological character into electricity. This electricity may subsequently become an interesting source of income. The system may be proposed to agricultural companies as well as to municipality corporations.
The process of fermentation may be carried out as dry fermentation or as liquid fermentation. Dry fermentation, working with materials where the percentage of dry matter exceeds 15%, is the topic of this paper. This method has been frequently discussed as a method of processing organic material without waste water and thus the volume of material as well as the size of the biogas plant considerably decreases. To enable progress in the process, it is necessary to use a biologically active liquid solution containing the essential micro-organisms, often termed "percolate". To activate a fresh substrate, fermented material adulterant containing cultivated microorganisms from previous processes is used; the ratio in which it is used is approximately one third to one fifth. "Percolate strategy" is another phrase used for sustaining the anaerobic fermentation; material is sprinkled on the percolate in the precisely defined cycles. In addition, the biologically active liquid solution contains organic substances washed out from the fermented material. With regard to its amount, this paper has become an impulse for the research in the amount of biogas which may be subsequently produced from the percolate in the so-called biofilm reactor. An external reactor with a cultivated bacterial biofilm on an immovable carrier with the percolate flowing through it has been constructed in laboratory conditions for this purpose. The choice of suitable percolate strategy (this means the frequency of sprinkling) and the amount of percolate directly influences the process of anaerobic fermentation.

biogas, dry anaerobic fermentation, percolate strategy, farm waste, fermentation residue, biofilm reactor

Biologically degradable waste represents a considerable part of all waste being created in households as well as within industry. The terms biomethanization, anaerobic fermentation or anaerobic digestion have been encountered with increasing frequency within the specialized literature in connection with sustainable sources of energy. Anaerobic fermentation is a process in which almost any organic mass may be transformed into an energetically rich biogas and a fermentation residue. Only strictly anaerobic microorganisms enter into the process; thus the process may take place only in hermetically sealed environment.

A wide range of aerobic microorganisms participate in the process at the beginning. Then comes the anaerobe facultative and lastly the bacteria strictly necessitating the absence of oxygen. These produce methane which is one of the two basic elements of biogas. Even the smallest amount of oxygen present results in their perishing and the whole process of anaerobic stabilisation comes to an end (STRAKA, 2006).

The process of fermentation may be carried out as dry fermentation or as liquid fermentation. Dry fermentation, working with materials where the percentage of dry matter exceeds 15% (25% and even more as presented in different sources), is a frequently discussed topic nowadays. It is a method of processing organic material without waste water and thus the volume of material as well as the size of the biogas plant considerably decreases.

The problem of draining the digestive has been frequently discussed in the field of raw materials and biological waste processing (in the branch of liquid anaerobic fermentation). Thus, it is more than possible that dry fermentation, capable of processing the material with a dry matter percentage of up to 60%, will become more competitive with "traditional biogas plants".

The issue of processing biodegradable waste by the method of dry fermentation may be denoted as very rarely spread within the Czech Republic and Slovakia. There are only two facilities in operation within the whole of the Czech Republic. The founders of the idea of dry fermentation are the German companies Bekon and Bioferm. Companies which use the system with continual operation are Dranco (Belgium), Kompogas (Switzerland), Anacom (Switzerland), and Valorga (France). These technologies are suitable for the mechanical-biological adjustment of communal waste and are suitable for use within the community sphere (BRKO).

With regard to the world wide situation, where the increase in the proportion of the energy from sustainable sources is demanded, anaerobic fermentation offers a possibility of transforming farm waste, farm products, municipality waste of biological character into electricity. This electricity may subsequently become an interesting source of income for various subjects. The offer may be proposed to agricultural companies as well as to municipality corporations. Two years ago, the technologies producing "renewable energy", especially the photovoltaic technology, which has so often become a victim of financial speculation, experienced a start with a rocket speed. Nowadays, a more cool-headed approach to the division of the sources of energy has been taken. This gives a big chance for biomass processing to stand out from other sources. The "photovoltaic boom" has created a media portrayal which has thrown other technologies and sustainable sources of energy into the shade. Nonetheless, new, promising technologies have come into existence and there is still a lot to explore, research and develop.

The aim of this paper is to analyze the conduct of biological materials processed via dry fermentation in laboratory conditions and in the experimental facility; then to compare the biogas yield with the standard values. The methane biofilm reactor has been found to increase the biogas yield; this reactor has been inserted between the substrate reactor and percolate tank. The process of mechanization running for 26 to 33 days has been depicted in the graphs. A partial aim of this paper is to assign and asses the percolate strategy by means of statistical dependence. The aim is to describe the influence of the percolate amount and the number of the percolate cycles on the volume of the produced biogas. The reduction potential and pH are other benchmark values.

MATERIALS

Commonly accessible materials were used within the course of the research. These were the materials originating from the every day operation of a co-operative farm. The most frequent material used in biogas plants is maize silage, in a mixture with grass silage, cattle manure from the beef bull bedding and chicken manure. It is necessary to be extremely cautious in batching the chicken manure because of the high content of nitrogen. However, this material is very frequently an extremely demanded commodity due to its high energetic content. Beer grains, coming into existence as a waste product of beer production, serves to complement to the above mentioned commodities. The materials used have been obtained from a co-operative farm breeding livestock, layers being bred with an outlet, an agricultural biogas plant and a brewery. Tab. I demonstrates the general characteristics of the input materials.

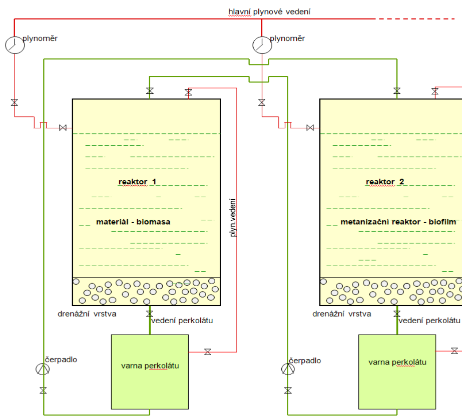
I: *Materials in experiment – general characteristics*

Material	Dry matter. [%]	Organic dry matter [%]	N [% dry matter.]	NH_4 [% dry matter]	P [% dry matter]	Biogas yield [m^3*kg.$10^{-3}$$_{FM}$]*	Gas yield [m^3*kg.10^{-3} organic dry matter]	CH_4 content [%]
Maize silage	20–30	85–95	1.1–2	0.15–0.3	0.2–0.3	170–200	450–700	50–55
Cattle manure	25	68–76	1.1–3.4	0.22–2	1–1.5	40–50	210–300	60
Grass silage	25–50	70–95	3.5–6.9	6.9–19.8	0.4–0.8	170–200	550–620	54–55
Chicken faeces	32	63–80	5.4	0.39	-	230–260	500–650	60
Beer grains	20–25	70–80	4–5	-	1.5	105–130	580–750	59–60

* FM – fresh mass

A brief characteristic of the experimental facility

The experimental facility consists of a set of two reactors and two tanks with percolate; the percolate volume is 60 liters. The tanks are located underneath the reactors. Both reactors are of identical size and construction (see Fig. 1). They are constructed from plastic barrels with the capacity of 100 liters and an air-proof cover. The reactors are located in a box with thermal insulation; the temperature is set at 38 °C ± 2 °C (a mesophilic process). There is a jet installed in the middle of the cover; the jet applies the percolate. The lower part of the reactor (grit dry area covered with fine gauze) provides protection against the solid substance being washed out into the tank with percolate. The substrate reactor contains biomass. The biofilm reactor contains bacterial biofilm cultivated on an immovable carrier. Plastic "balls" of a large surface, which are being used in sewage disposal plants, serve as the immovable carrier. A perforated shed of a pyramid shape with a diameter 30 cm ensures the even distribution of the sprinkled percolate. The shed is loosely laid in the material. This ensures the even application of the percolate and protects against the emergence of so-called "dry shaft" with the material becoming inactive.



1: *The Construction and connection of the substrate and mechanization reactor*

METHODS

To start the fermentation process, the inoculation of the material with a biologically active substance is necessary. This substance is called percolate; it is a biologically active water solution containing anaerobic bacteria and organic substances washed out from the material.

Within the experiment, the process is activated by the complete submerging of the material in percolate for 24 hours. The process immediately takes off and after the residual oxygen is depleted, methane starts to be produced in the reactor.

Fermentation residue from the biogas plant has been used as percolate; this plant is operated on a mixture of 65% maize silage, 20% grass silage and 15% pig slurry. It is necessary to strain the fermentation residue with the average amount of dry matter 6.3% through a strainer with a 1 mm loop to separate large elements, especially long filaments from plant tissues and thus prevent the circulating pumps from being obstructed during the percolate cycles. The fermentation residue is adjusted so that the amount of dry matter is 2% and the average pH is 8.14 ± 0.3.

The choice of suitable percolate strategy (this means the frequency of sprinkling) and the amount of percolate, directly influences the process of anaerobic fermentation. The influence of the percolate strategy on the biogas production may, from the perspective of statistics, be expressed by the following formula of statistical dependency:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}},$$

where

r..... coefficient of correlation,

(x_1,y_1), (x_2,y_2), … (x_n,y_n)..........real values of numerical sequences.

If the coefficients of correlation of the numerical sequences for the biogas production and percolate strategy in time are compared, we will find out the actual delay and mutual influence of the two.

With regard to the amount of the washed out substances, this paper has become an impulse for the research in the amount of biogas which may be subsequently produced from the percolate in the so-called biofilm reactor.

Method of measuring

Measuring proceeded in accordance with the standard No. VDI 4630 Fermentation of organic materials – Characterisation of the substrate, sampling, collection of material data, fermentation tests.

- Material weighting, capacity measuring, specification of dry matter and organic dry matter (at the temperature of 60 °C and 105 °C).
- Closure of the reactor with fresh material and the fermentation process initiation by submerging in percolate for 24 hours.
- Monitoring the amount of produced biogas (gasometer Ritter TG 05) and the constituents of the biogas: CH_4, CO_2, O_2 (Gasanalysator Ansyco GA 94). Reduction potential and pH continuous measuring (pH meter WTW Multi 340i).
- Choice of percolate strategy (number of sprinkling cycles a day and the amount of percolate).
- Percolate strategy has been adjusted on the basis of the biogas production and the character of material (its permeability).

- Measuring at an interval of one day and recording it in minutes.
- Graphic evaluation of the experiment.

RESULTS AND DISCUSSION

Maize Silage

The results of the anaerobic fermentation measuring are stated as average values obtained from three tests; each being carried out in two repetitions. The following values have been measured: pH in the interval from 7.54 to 9.97, the average reduction potential was −53.03 ± 7.88 [mV].

234.99 liters of biogas were created in the substrate reactor and the mechanization reactor within 30 days. It was related to 1 kg FM* with the average methane content 52.1 %, which means an increase of 6.8 %, and up to 38.2 % when compared with the reference value of 170–200 $m^3*kg.10^{-3}{}_{FM*}$. The substrate reactor was responsible for 42.3 % of the overall biogas production while the mechanization reactor produced 57.7 % of the biogas.

Statistical evaluation of the correlation between the percolate strategy and biogas production

Percolate strategy:

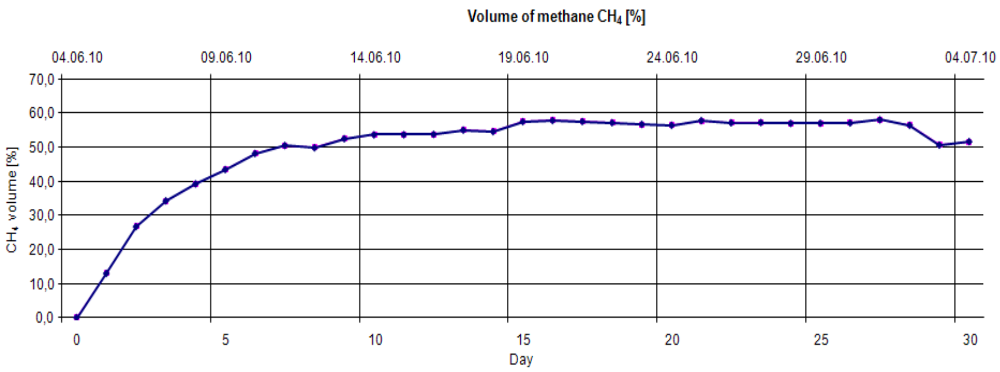
Day 0–30 $l.d^{-1}$ – material being inoculated by submerging
Day 1 to 3 and 6 to 9–27.6 $l.d^{-1}$ (4.6 l* 6 cycles)

II: *Maize silage measuring results*

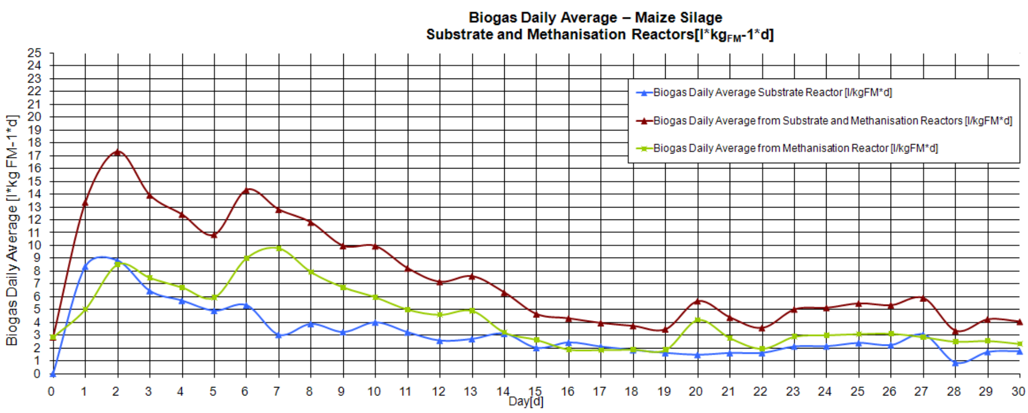
Batch – biomass	$m_{substrate}$ =	11,6	kg
Biomass density	11,6 kg / 30 l	0,387	kg/l
Volume of water	$W_{substrate}$ =	14,36	% (related to humidity)
Dry matter	TSb_{iomass} =	85,64	%
Dry matter	$TS_{Biomasse}$ =	9,93	kg
Dry matter density	9,93480410555198 kg / 30 l	0,331	kg/l

Maize silage data – Biogas	Maize silage [l of biogas/l of substrate]	Maize silage [l of CH4/l]	Maize silage [l of biogas/ kg of dry matter]	Maize silage [l of CH4/kg of dry matter]	Maize silage [l of biogas/ kg of organic dry matter]	Maize silage [l of CH4/ kg of organic dry matter]	Maize silage [l of CH4/kg of FM]
After 30 days	37,64	17,18	343,16	155,38	318,85	144,55	67,11

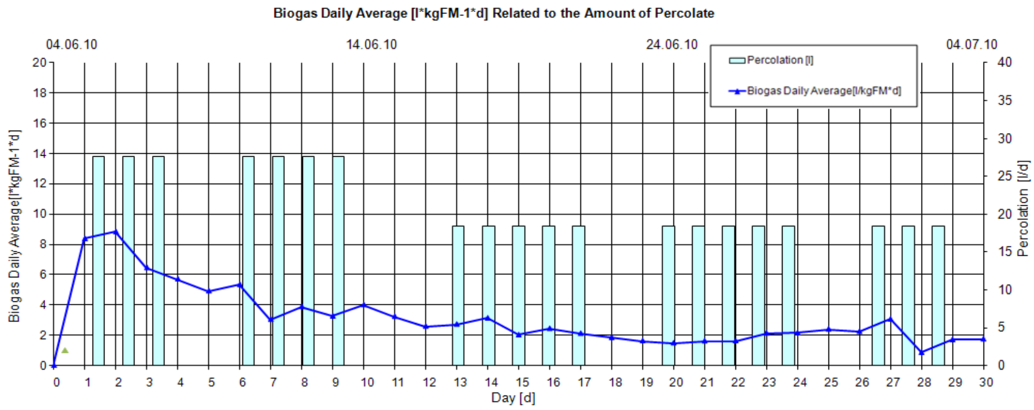
Experiment data	Maize silage [l of biogas/kg of FM]	Methanization reactor [l of biogas/kg of FM]	Substrate and methanization reactors [l of biogas/kg of FM]
After 30 days	99,23	135,76	234,99



2: *Proportion of methane (%) in biogas from maize silage*



3: *Daily production of biogas ($l.kg^{-1}{}_{FM}.d$) from maize silage in substrate reactor and methanisation reactor*



4: *Daily production of biogas (l.kg$^{-1}_{FM}$.d) from maize silage and percolation (l.d^{-1})*

Day 13 to 17, 20.to 24, 26 to 29 –18.4 l.d^{-1} (4.6 l* 4 cycles).

Percolation was not in progress during weekends due to the absence of operating personnel.

The following coefficient of correlation graph depicts the response of the percolate strategy on biogas production. The average absolute coefficient of correlation r equals 0.39. That means that the percolate strategy influences the biogas production with the delay of 6 days. On the contrary, when the material was submerged in percolate at the beginning of the experiment, the reaction was immediate (after only one day). This proves the inoculation as being successful.

The increase in the biogas yield of up to 38.2% compared to standard values may be explained by the usage of the energy from the fermentation residue. The mechanization reactor proved its functionality as the decomposition of the larger proportion of the washed out substances took place in it. The average percentage of methane, 52.1% falls into the interval which is presented in Karafiát Z., Vítěz T.: 2009; the interval being 50–55%. The biogas production is also comparable after conversion and it falls within the interval of 190 l.d^{-1} ± 2 l. The pH value in the interval from 7.54 to 7.97 corresponds with the pH values from 5.8 to 8.6 as presented by Karafiát and Vítěz. Stable negative reduction potential indicates an anaerobic environment in the reactors and a fair process of fermentation.

Cattle Manure

The results of the anaerobic fermentation measuring of cattle manure are stated as average values obtained from two tests, each being carried out in two repetitions. The following values have been measured: with the pH between 7.83 and 8.26, the average reduction potential was –60.6 ± 5.6 [mV].

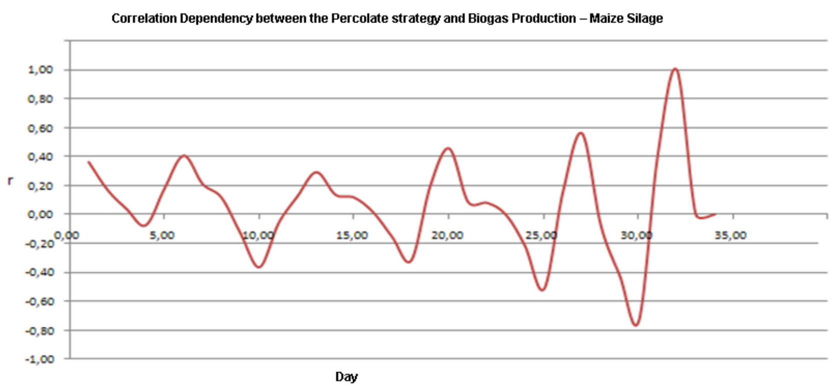
158.24 liters of biogas were created in the substrate reactor and mechanization reactor within 33 days. It was related to 1 kg FM* with an average methane content of 45.0%, which means an increase of 216.5% up to 295.6% when compared with the reference value of 40–50 m^3*kg.10$^{-3}_{FM*}$. The substrate reactor produced 61.2% and the mechanization reactor produced 38.8% of the overall biogas production.

Statistical evaluation of the correlation between the percolate strategy and biogas production

Percolate strategy:

Day 0 – 30 l.d^{-1} – material being inoculated by submerging
Day 1 – 4.6 l.d^{-1} (4.6 l* 1 cycle)
Day 2, 5 to 9, 12 to 16, 19 to 20 – 27.6 l.d^{-1} (4.6 l* 6 cycles)
Day 21 to 23, 26 to 30 – 18.4 l.d^{-1} (4.6 l* 4 cycles).

Average coefficient of correlation r = 0.63 means a high dependency of the percolate strategy on biogas production with the delay of 4 days. The positive reaction on the material submerging (for 24 hours) appeared with the delay of 2 days.



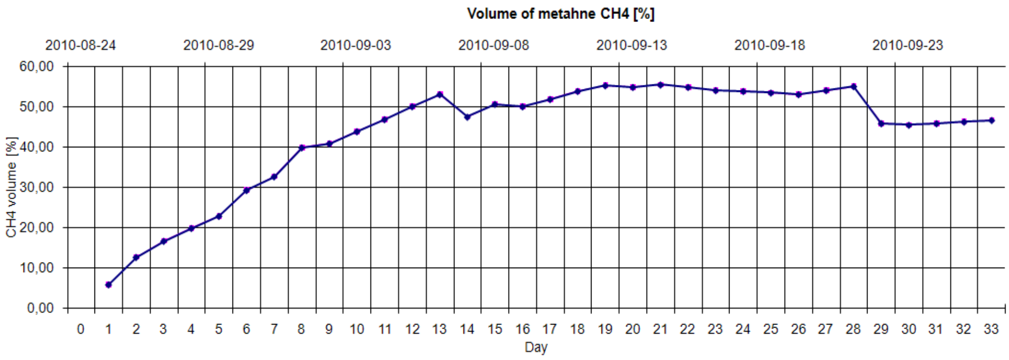
5: *Correlation of percolate strategy and biogas production from maize silage*

III: *Cattle manure measuring results*

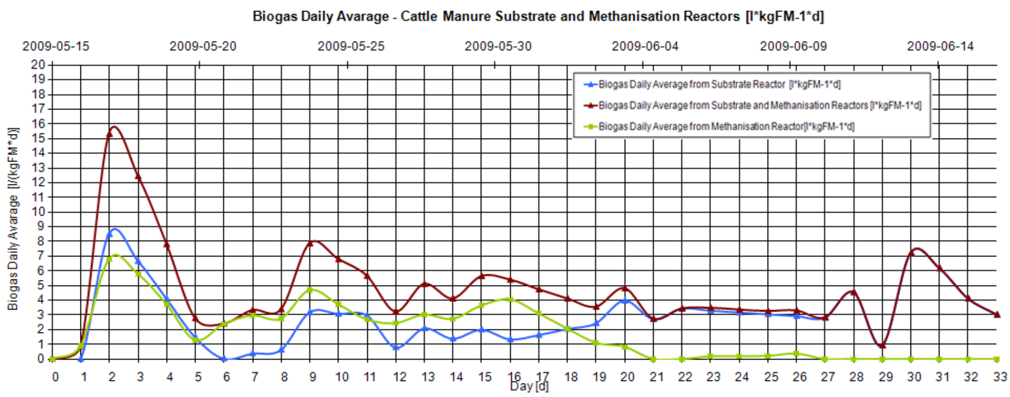
Batch – biomass	$m_{substrate}$ =	11,63	kg
Biomass density	11,63 kg / 30 l	0,388	kg/l
Volume of water	$W_{substrate}$ =	83,95	% (related to humidity)
Dry matter	TSb_{iomass} =	16,05	%
Dry matter	TSb_{iomass} =	1,87	kg
Dry matter density	1,866615 kg / 30 l	0,062	kg/l

Cattle manure data – Biogas	Cattle manure [l of biogas/l of substrate]	Cattle manure [l of CH4/l]	Cattle manure [l of biogas/ kg of dry matter]	Cattle manure [l of CH4/kg of dry matter]	Cattle manure [l of biogas/ kg of organic dry matter]	Cattle manure [l of CH4/ kg of organic dry matter]	Cattle manure [l of CH4/kg of FM]
After 33 days	37,51	16,06	602,81	258,08	501,42	214,67	41,42

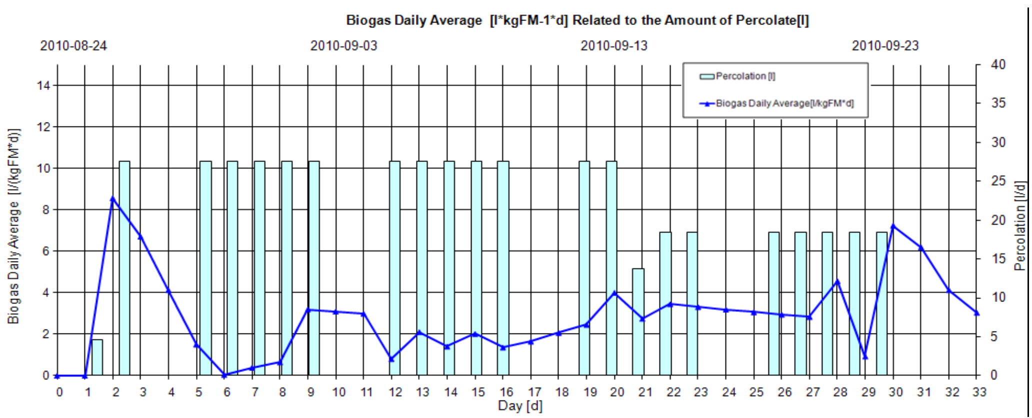
Experiment data	Cattle manure [l of biogas/kg of FM]	Methanization reactor [l of biogas/kg of FM]	Substrate and methanization reactors [l of biogas/kg of FM]
After 33 days	96,75	61,49	158,24



6: *Proportion of methane (%) in biogas from cattle manure*



7: *Daily production of biogas* (*l.kg*$^{-1}$$_{FM}$*.d*) *from cattle manure in substrate reactor and methanisation reactor*



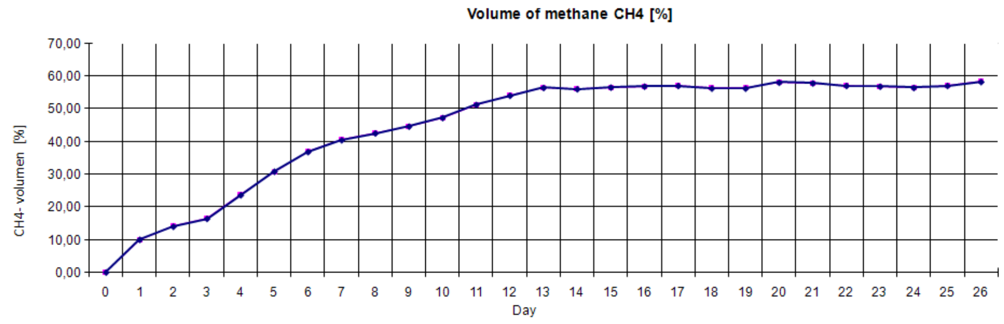
8: *Daily production of biogas* (*l.kg*$^{-1}$$_{FM}$*.d*) *from cattle manure and percolation* (*l.d*$^{-1}$)

IV: *Grass Silage Measuring Results*

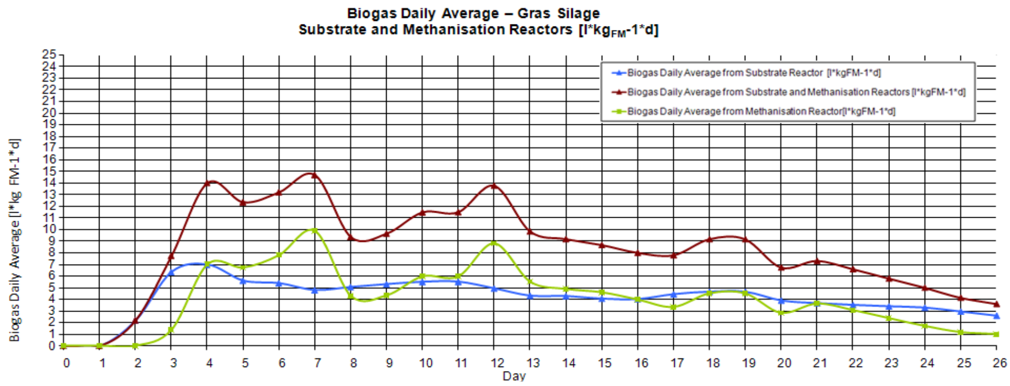
Batch – biomass	$m_{substrate}$ =	5,43	kg
Biomass density	5,43 kg / 30 l	0,181	kg/l
Volume of water	$W_{substrate}$ =	30,90	% (related to humidity)
Dry matter	TSb_{iomass} =	69,10	%
Dry matter	$TS_{Biomasse}$ =	3,75	kg
Dry matter density	3,75213 kg / 30 l	0,125	kg/l

Gras silage data – Biogas	Gras silage [l of biogas/l of substrate]	Gras silage [l of CH4/l]	Gras silage [l of biogas/ kg of dry matter]	Gras silage [l of CH4/kg of dry matter]	Gras silage [l of biogas/ kg of organic dry matter]	Gras silage [l of CH4/ kg of organic dry matter]	Gras silage [l of CH4/kg of FM]
After 26 days	22,26	9,96	161,87	72,58	145,29	65,15	50,16

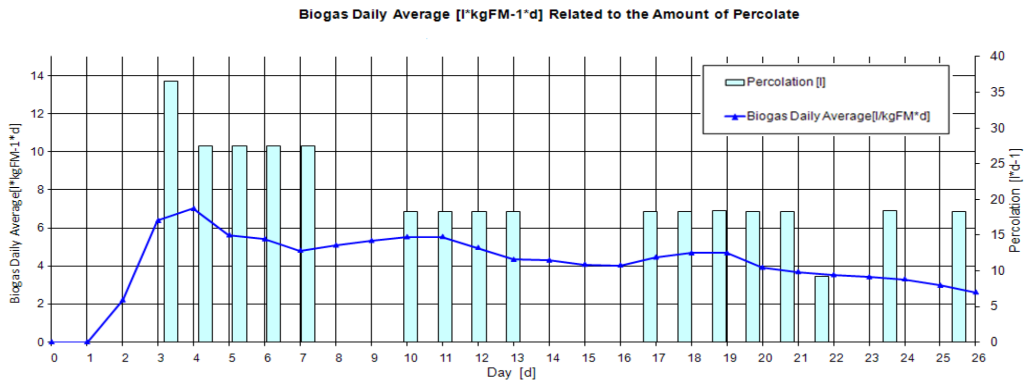
Experiment data	Gras silage [l of biogas/kg of FM]	Methanization reactor [l of biogas/kg of FM]	Substrate and methanization reactors [l of biogas/kg of FM]
After 26 days	111,85	109,45	221,30



9: *Proportion of methane (%) in biogas from grass silage*



10: *Daily production of biogas (l.kg^{-1}$_{FM}$.d) from grass silage in substrate reactor and methanisation reactor*



11: *Daily production of biogas (l.kg^{-1}$_{FM}$.d) from grass silage and percolation (l.d^{-1})*

The increase in the biogas yield of up to 295.6% compared to standard values may be explained by the usage of the energy from the fermentation residue. This residue energy exceeded many times the biogas production solely from manure. The biogas production from cattle manure was biased in this experiment due to the percolate volume of 60 l; under normal conditions, the production is rather low. The average percentage of methane 45.0% is significantly lower than the interval from 55 to 60% as presented in Karafiát and Vítěz. Daily biogas production of 138 $l.d^{-1}$ is 2.3 times higher than the Karafiát and Vítěz results of 30–60 $l.d^{-1}$. The pH value is also from 0.03 to 0.46 times higher. Exceeding production of biogas of poor quality with a high CO_2 ratio is the cause. Stable negative reduction potential –60.6 [mV] indicates a fair fermentation process.

Grass silage

The results of anaerobic fermentation measuring are stated as average values obtained from two tests; each being carried out in two repetitions. The following values have been measured: with the pH between 7.44 and 8.08, the average reduction potential was –53.0 ± 8.13 [mV].

221.30 liters of biogas were created in the substrate reactor and mechanization reactor within 26 days. It was related to 1 kg FM* with an average methane content of 45.2%, which means an increase of 10.7% up to 30.3% when compared to the reference value of 170–200 $m^3*kg.10^{-3}{}_{FM*}$. The substrate reactor produced 50.5% and the mechanization reactor produced 49.5 % of the overall biogas production.

Statistical evaluation of the correlation between the percolate strategy and biogas production

Percolate strategy:

Day 0 – 30 $l.d^{-1}$ – material being inoculated by submerging
Day 1 and 2 without percolation (weekend)
Day 3 – 36.8 $l.d^{-1}$ (9.2 l* 4 cycles)
Day 4 to 7 – 27.6 $l.d^{-1}$ (4.6 l* 6 cycles)
Day 10 to 13, 17 to 21, 24 and 26 – 18.4 $l.d^{-1}$ (9.2 l*2 cycles).

Average coefficient of correlation r = 0.39 means medium dependency of the percolate strategy on biogas production with the delay of 6 days. The positive reaction on the material being submerged (for 24 hours at the beginning of the experiment) appeared with the delay of 2 days.

Average content of methane 45.2% proves Karafiát and Vítěz's measuring; they present the methane content from between 47 to 52%. The pH value from 7.44 to 8.08 corresponds with the pH interval from 7.3 to 8.0 presented by Karafiát. Stable reduction potential –53.0 [mV] indicates anaerobic environment.

Chicken faeces

The results of the chicken manure anaerobic fermentation measuring are stated as average values obtained from two tests; each being carried out in two repetitions. The following values have been measured: with the pH between 7.40 and 8.42, the average reduction potential was –70.6 ± 10.8 [mV].

415.46 liters of biogas were created in substrate the reactor and mechanization reactor within 32 days. It was related to 1 kg FM* with the average methane content 49.7%, which means an increase of 80.6% up to 89.8% when compared to the reference value of 230–260 $m^3*kg.10^{-3}{}_{FM*}$. The substrate reactor produced 68.2% and the mechanization reactor produced 31.8% of the overall biogas production.

Statistical evaluation of the correlation between the percolate strategy and biogas production

Percolate strategy:

Day 1 – 38 $l.d^{-1}$ – material being inoculated by submerging
Day 2 and 3 without percolation (weekend)
Day 3 to 5, 14, 18 to 21, 25 and 26 – 20.7 $l.d^{-1}$ (6.9 l* 3 cycles)
Day 7, 10, 24, 27 – 27,6 $l.d^{-1}$ (6.9 l* 4 cycles)
Day 12 and 13 – 34.5 $l.d^{-1}$ (6.9 l* 5 cycles)
Daily biogas production from day 28 on was irrelevant.

Average coefficient of correlation r = 0.39 means medium dependency of the percolate strategy on biogas production with the delay of 4 days. The positive reaction on the material submerging (for 24 hours at the beginning of the experiment) appeared with the delay of 1 day. The reduction potential of –70.6 ± 10.8 [mV] indicated a very stable anaerobic environment. Higher biogas production may be explained by the organic substances being washed out into the mechanization reactor where they were fully used by the bacterial biofilm.

Beer grains

The results of the beer grains anaerobic fermentation measuring are stated as average values obtained from one test being carried out in two repetitions. The following values have been measured: with the pH between 7.44 and 8.08, the average reduction potential was –53.1 ± 8.1 [mV].

157.19 liters of biogas were created in the substrate reactor and mechanization reactor within 32 days. It was related to 1 kg FM* with the average methane content 46.4 %, which means an increase of 20.9% up to 49.7% when compared to the reference value of 105–130 $m^3*kg.10^{-3}{}_{FM*}$. The substrate reactor produced 53.5% and the mechanization reactor produced 46.5% of the overall biogas production.

Statistical evaluation of the correlation between the percolate strategy and biogas production

Percolate strategy:

Day 1 – 30 $l.d^{-1}$ – material being inoculated by submerging
Day 3 to 5, 14, 18 to 21, 25 and 26 – 20.7 $l.d^{-1}$ (6.9 l* 3 cycles)
Day 7, 10, 24, 27, 28 – 27.6 $l.d^{-1}$ (6.9 l* 4 cycles)
Day 12 and 13 – 3.5 $l.d^{-1}$ (6.9 l* 5 cycles)
Day 30 – 9.2 $l.d^{-1}$ (4.6 l* 2 cycles).

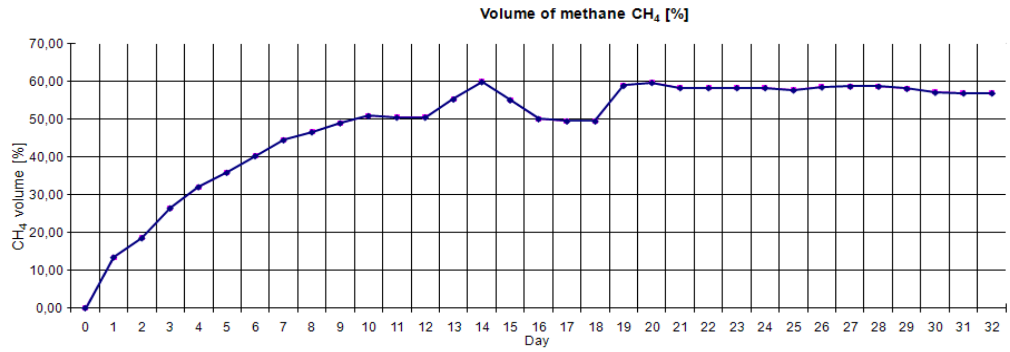
Average coefficient of correlation r = 0.41 means medium dependency of the percolate strategy on biogas production with the delay of 4 or 5 days. Extremely long positive reaction on the material submerging (for 24 hours at the beginning of the experiment) appeared with the delay of 4 days.

V: *Chicken faeces measuring results*

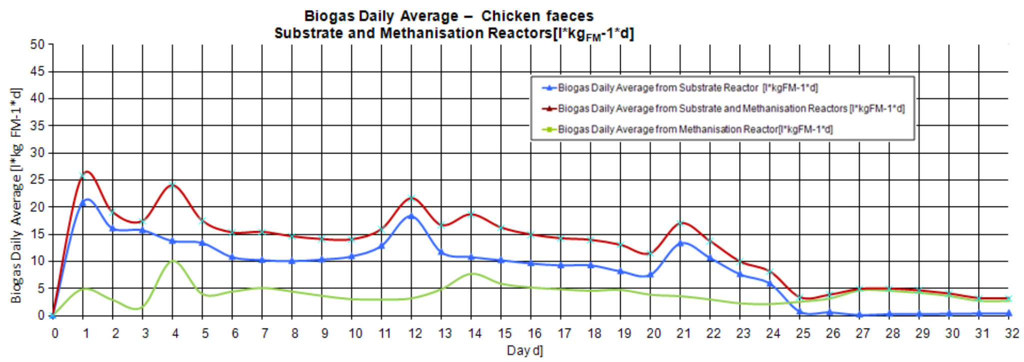
Batch – biomass	$m_{substrate}$ =	7,9	kg
Biomass density	7,9 kg / 25 l	0,316	kg/l
Volume of water	$w_{substrate}$ =	67,96	% (related to humidity)
Dry matter	$TS_{biomass}$ =	32,04	%
Dry matter	$TS_{biomass}$ =	2,53	kg
Dry matter density	2,53116 kg / 25 l	0,101	kg/l

Chicken faeces data – Biogas	Chicken faeces [l of biogas/l of substrate]	Chicken faeces [l of CH4/l]	Chicken faeces [l of biogas/ kg of dry matter]	Chicken faeces [l of CH4/kg of dry matter]	Chicken faeces [l of biogas/ kg of organic dry matter]	Chicken faeces [l of CH4/ kg of organic dry matter]	Chicken faeces [l of CH4/kg of FM]
After 32 days	61,19	38,11	883,91	380,30	573,66	246,81	121,85

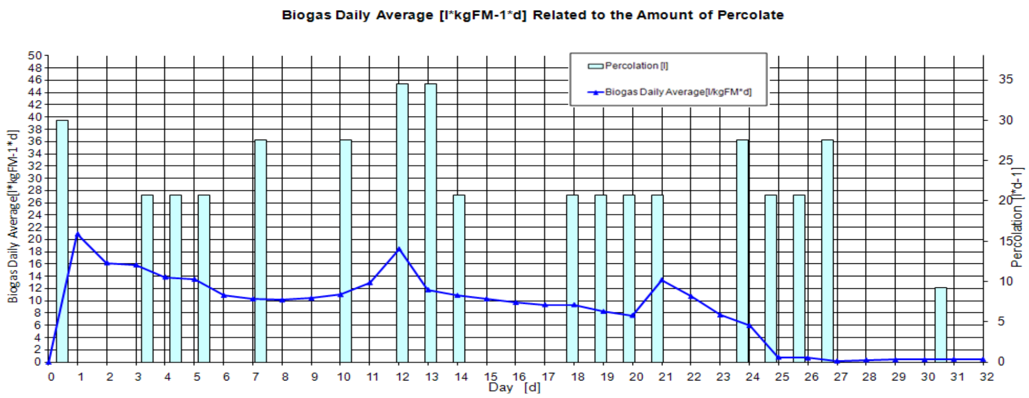
Experiment data	Chicken faeces [l of biogas/kg of FM]	Methanization reactor [l of biogas/kg of FM]	Substrate and methanization reactors [l of biogas/kg of FM]
After 32 days	283,20	132,26	415,46



12: *Proportion of methane (%) in biogas from chicken manure*



13: *Daily production of biogas (l.kg^{-1}$_{FM}$.d) from chicken manure in substrate reactor and methanisation reactor*



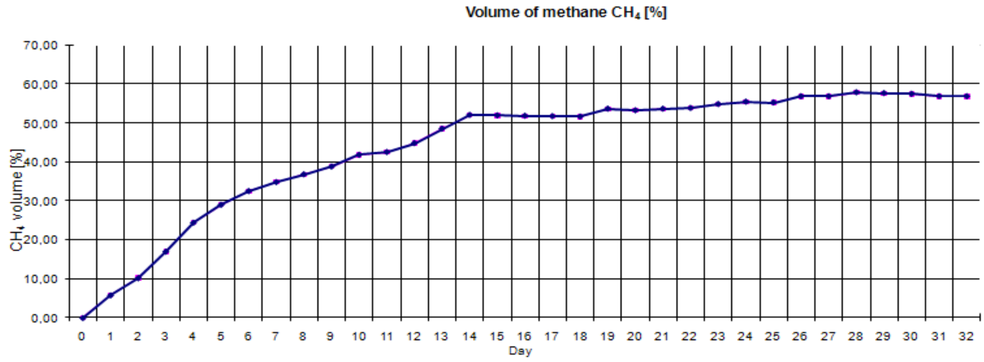
14: *Daily production of biogas (l.kg^{-1}$_{FM}$.d) from chicken manure and percolation (l.d^{-1})*

VI: *Beer grains measuring results*

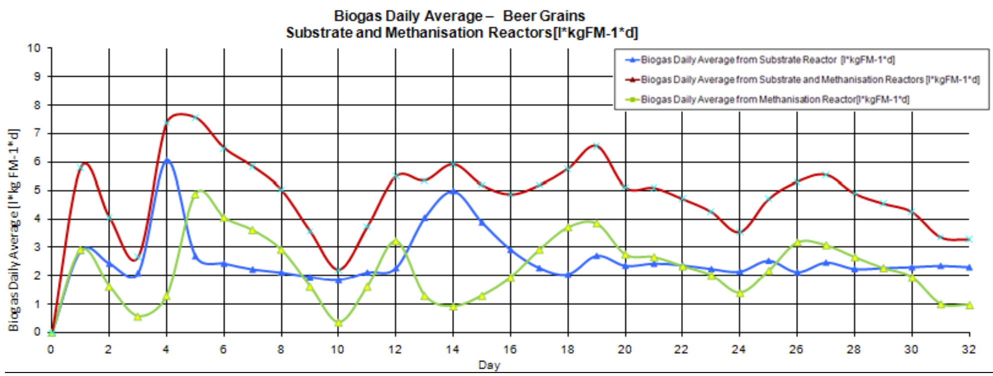
Batch – biomass	m[illegible] =	17,26	kg
Biomass density	17,26 kg / 30 l	0,575	kg/l
Volume of water	w[illegible] =	77,11	% (related to humidity)
Dry matter	TS[illegible] =	22,89	%
Dry matter	TS[illegible] =	3,95	kg
Dry matter density	3,950814 kg / 30 l	0,132	kg/l

Beer grains data – Biogas	Beer grains [l of biogas/l of substrate]	Beer grains [l of CH4/l]	Beer grains [l of biogas/ kg of dry matter]	Beer grains [l of CH4/kg of dry matter]	Beer grains [l of biogas/ kg of organic dry matter]	Beer grains [l of CH4/ kg of organic dry matter]	Beer grains [l of CH4/kg of FM]
After 32 days	41,50	17,48	367,47	154,83	356,63	150,26	35,44

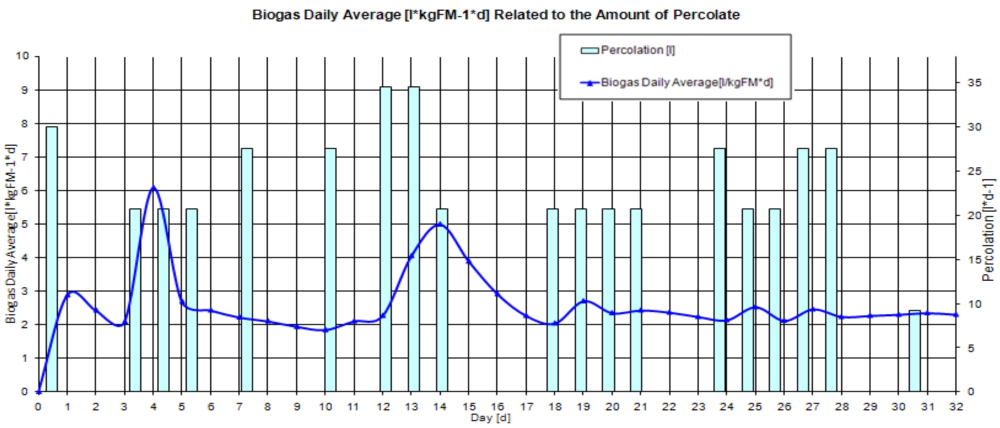
Experiment data	Beer grains [l of biogas/kg of FM]	Methanization reactor [l of biogas/kg of FM]	Substrate and methanization reactors [l of biogas/kg of FM]
After 32 days	84,11	73,08	157,19



15: *Proportion of methane (%) in biogas from beer grains*



16: *Daily production of biogas (l.kg$^{-1}{}_{FM}$.d) from maize silage in substrate reactor and methanisation reactor*



17: *Daily production of biogas (l.kg$^{-1}{}_{FM}$.d) from beer grains and percolation (l.d^{-1})*

The average reduction potential −53.1 ± 8.1 [mV] indicates a stable anaerobic environment. The mechanization reactors production of 46.5% of the overall biogas production proves large amounts of the organic substances were being washed out.

Biogas production evaluation compared to standard values

CONCLUSIONS

The idea of the use of a biofilm reactor within the dry fermentation process is not widely spread. However, this idea introduces the possibility of completing the cycle for currently operating biogas plants. The advantage of this system is the more continuous and stable process of dry fermentation outside the operating hours of the facility. It is possible to decompose the organic substances washed out of the material immediately after the batch closure due to the stable and fixed biomass in the biofilm reactor.

This work has proven and statistically described the dependency of biogas production on percolate strategy. The functionality of the mechanization reactor has also been proven to be almost one half of the overall biogas production (from the given material) . This work incites further development of the idea and offers the possibility of more effective and faster use of energy inherent in the form of organic substances in materials with the content of dry matter over 25%. This technology may be included, for example, within bio-mechanical waste treatment.

VII: *Measuring results chart – biogas percentage ratio compared to standard values*

Substrate	Biogas yield reference values [m^3*kg.10^{-3}_{FM}]	Overall biogas yield [m^3*kg.10^{-3}_{FM}]	Substrate reactor biogas yield [m^3*kg.10^{-3}_{FM}]	Methanization reactor biogas yield [m^3*kg.10^{-3}_{FM}]	Biogas volume compared to reference values [%]	Ratio of biogas from substrate reactor [%]	Ratio of biogas from methanization reactor [%]
Maize Silage	170–200	234.99	99.23	135.75	+6.8 up to +38.2	42.3	57.7
Cattle Manure	40–50	158.24	96.75	61.49	+216.5 up to +295.6	61.2	38.8
Grass Silage	170–200	221.46	111.76	109.79	+10.7 up to +30.3	50.5	49.5
Chicken Faeces	230–260	415.46	283.2	132.26	+80.6 up to +89.8	68.2	31.8
Beer Grains	105–130	157.19	84.11	73.08	+20.9 up to +49.7	53.5	46.5

SUMMARY

This work has succeeded in proving the direct dependency of percolate strategy on biogas production. Thus, the theory from Karafiát and Vítěz's research (2009: project No. 2A-3TP1/010) has been confirmed. They prove that the most significant influence on the amount of biogas production is the percolation intensity. In case of exceedingly intense percolation, the amount of produced biogas declines, as is the case with the amount of percolate not being sufficient. They claim that the percolation intensity setting plays one of the leading roles in the amount of produced biogas.
Biogas production reacted with medium or high statistical dependency on percolation with a delay of 4 to 6 days. However, the system reacted within the interval from one to four days with inoculation by complete submerging.
The experiment duration varied from 26 to 33 days. The materials used in the experiment were maize silage, grass silage, cattle manure, chicken manure and beer grains. Adjusted fermentation residue from the biogas plant has been used as percolate for each batch.
The aim of this work was to analyze the conduct of biological materials processed via dry fermentation in laboratory conditions and to compare the biogas yield with the standard values. The biogas production values obtained by measuring were by 6.8% higher than the standard values in the case of maize silage and up to 295.6% higher than the standard values in the case of cattle manure. This result may be explained by the use of residual energy inherent in the percolate in the methanization reactor; this proved the functionality of the methanization reactor. All tests were carried out with the pH between 7.40 and 8.42. The largest pH fluctuation appeared in the case of the chicken manure. Strictly anaerobic conditions in the reactors were monitored by means of reduction potential which

was within the interval from –53 to –70 [mV]. The confirmation of the biofilm reactor functionality and the publication of results offer wider practical use of this theory and facility. I suppose that with the use of this type of facility with fixed bacterial biofilm, the biogas plant operation would become more efficient and the biogas yield would increase in a shorter span of time. This supplementary facility is able to incite new biogas production shortly after a batch has been closed in the reactor because of the use of cultivated biomass.

This paper should incite further research into optimum percolate strategy during the dry fermentation process of biological material.

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