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ANALYSIS OF BIOGAS TRANSFORMATION IN EXPERIMENTAL BIOGAS PLANT

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Abstract

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The topic of this paper is the analysis of anaerobic fermentation in an experimental biogas plant. Technological processes and operation parameters were monitored; these processes and parameters include, for example, the optimal structure of the input material and the consideration of the prolonging of the duration of the fermentation process. The goal of prolonging the fermentation process is to obtain higher biogas (and methane) production and to decrease the fermentation residue effluvial emissions. Emphasis is also laid on the mutual co-fermentation of substrates with regard to further use of the results in solving technological problems in other biogas plants. This technological process was first monitored in 2009; that is, before the planned intensification and modernization of the experimental biogas plant. Thus, the evaluation of the process could become part of the planned intensification and modernization of the chosen biogas plant (extended by the addition of the second stage of methanogenesis). The results obtained from the experimental biogas plant, which is one of the pioneering biogas plants in the Czech Republic, may serve, to other biogas operators, as a base for the preparation of suitable input, and for improving the efficiency of anaerobic fermentation within their biogas plants. The goal of the improvement of the fermentation process is to fulfill the ecological aspects; that is, to cut down CO_2 emissions and to reduce the negative impact of the fermentation process on the environment (reduction of effluvium and noise originating in biogas plants).

renewable sources of energy, biogas, biogas plant, anaerobic fermentation, electricity production

Renewable sources of energy are (in the Czech Republic) non-fossil fuel natural energy sources; these are water energy, wind energy, solar energy, solid biomass and biogas energy, energy from the environment, geothermal energy and liquid biofuel energy. The European Commission introduced the first Action Plan for Energy Efficiency at the end of 2006. One of the goals of the action plan is raising the ratio of the energy from renewable sources to 20% by 2020; for the Czech Republic, the ratio is 13%. Another landmark in European energy politics was The Treaty of Lisbon ratification in 2009. Four main goals of The Treaty of Lisbon were established. One of the goals was to support the development of new sources of renewable energy (THE CZECH REPUBLIC GOVERNMENT RESOLUTION, 2009).

Anaerobic fermentation of organic substances (including the biodegradable waste) seems to be one of many alternatives for utilizing renewable sources of energy. Biogas and biogas systems represent the energy sources with a highly positive contribution to environmental protection and formation. Although biogas is not able to push fossil fuels out of their dominant position in the energy market, it has unlimited perspectives for future utilization (in contrast to fossil fuels). Waste from agricultural and food processing enterprises may be disposed of by the anaerobic fermentation process. This waste may, in an unprocessed state, present a burden for the environment and/or cause contamination dangerous to livestock and people as well. Anaerobic fermentation and co-fermentation of herbal material is becoming one of the most advantageous ways of utilizing these waste materials. This situation has been brought about by the increasing need of **"pure"** energy, the decreasing reserves of solid fuels and the insufficiency of fossil fuels.

Biogas production technology is based on anaerobic fermentation (with the absence of oxygen). Within the course of anaerobic fermentation, microorganisms decompose the organic matter in the biogas plant and biogas is released as a consequence. This biogas may be further utilized, for example, by burning it in cogeneration units and thus producing electricity and heat. The methane bacteria activity may be divided into four phases within the course of this metabolism: hydrolysis, acidogenesis, acetogenesis and methanogenesis (STRAKA, 2006). Biogas is a transparent gas consisting predominantly of methane (CH_4) and carbon dioxide (CO_2). It may also contain small amounts of nitrogen (N_2), sulphate (H_2S), ammonia (NH_3), water (H_2O), ethane (C_2H_6) and other hydrocarbons with a lower content of carbon. Fermentation residue is a by-product of the process. The residue is utilized (depending on the input substrates used) as fertilizer of high quality which may be either applied directly on agricultural lots or may serve as material for compost production.

The goal of this dissertation thesis is to get an insight into the anaerobic processing of substrates with detailed specialization in the fermentation process in the chosen experimental biogas plant. The thesis deals with the background data essential for the execution of the second stage of the fermentation process in the chosen biogas plant; and subsequent evaluation of the extension and modernization of the biogas plant. Biogas processes treating certain input substrates was monitored in a one-month operation; the goal of monitoring was to process the data aiming at the most effective biogas production, or rather electricity production, depending on the input substances and other external influences. Practical measuring of the following parameters was used to assess the production; the parameters were: the volume, content and proportion of input materials, the delay in process, methane production and electric and thermal output. Subsequently, the fermentation process is described in the course of the biogas plant rebuilding and modernization. The same conditions were observed (volume, content and proportion of input materials, the delay in process and methane production).

MATERIALS AND METHODS

General characteristics of the experimental biogas plant operation

For the needs of this dissertation thesis, the materials used were obtained from an experimental biogas plant from daily operation outputs. The biogas plant started its operation in 1995, among the first in the Czech Republic. The plant is single-staged and it is a part of the technology in a pig breeding farm. Its performance is 900 kW_{el}. The biogas plant was built as single-staged with the purpose of treating agricultural waste from the agricultural production in the municipality. The treated waste is mainly pig slurry, silage and sugar refining chops which the farmers (as they are the producers of sugar beet) must take back from the sugar refineries. The input materials are not delayed longer than 40 days, on average.

Technology and technical facilities in chosen biogas plant

The monitoring and measuring of the anaerobic fermentation technological process was carried out in a chosen biogas plant. It was essential to assess the biogas process in the "old" biogas plant which was in operation until 1995 and in the "new" plant (that means the same one with increased input tank volume, after the addition of two new fermentation residue storehouses with the capacity of approximately 5 000 m^3, the extension of the biogas reactor and an increase in the number of co-generation units). The first measurement took place in 2009 and the second measurement (the comparative measurement) took place in 2011; that was within the course of re-building after the capacity was raised and the fermentation process was modernized.

Anticipated work flow was in accordance with planning and documentation preparation for the biogas plant modernization. The comparison of values measured in every day operation followed.

I: *Biogas plant basic characteristic; years 2009 and 2011*

Characteristic	Unit	2009	2011 (planned situation)
Number of co-generation units with the output of 150.500 kW_e	Pc	6	8
Installed output (Number of co-generation units x 150.500 kW_e)	kW_e	900	1 900
Operation status	-	Permanent	Permanent
Active fermenter volume	m^3	2 500 + 2 500	5 000 + 5 000
Electric output utilization (from the installed output)	%	55	70
Working days (minus lay-by days)	Day	359	365
Annual operation fund	Hour	8 616	8 760
Anticipated annual utilization	Hour	4 739	6 132
Annual production	kWh	4 264 920	4 869 100
Average daily output (345 days)	kWh	11 880	14 113

All practical measuring was carried out within the everyday operation of the biogas plant. Detailed description is in dissertation thesis, including graphical comparison.

Unfortunately, a delay occurred in the midst of the planning and technical preparation, thus the time schedule for works was breached. Although the biogas plant is now in operation, it is at the beginning of the field test only; this state continues at the present during construction. This delay was mainly caused by the long time frame that it took the EIA and IPPC for issuing their statement on the problematic. That means that, at present, the experimental biogas plant does not perform at 100 % of the field test operation as was anticipated.

The biogas plant has become a facility for waste treatment of other producers (according to Act No. 185/2001 Coll. on Waste) because of the use of extrinsic waste as the input substrate. 90 million kilograms of fermentation residue has annually been produced; the residue contains a high proportion of organic substances.

Monitoring biogas production dependent on the input substrate within the interval of 30 days – methods of evaluation of biogas plant operation before intensification and modernization of the fermentation process

The biogas plant operation was monitored at a defined interval; the interval is three months. The monitoring period was 30, or rather 31 days. Information about all input materials was recorded; the records started with the information of their weight and dry matter ratio and ended with the information of the overall electricity production. The same measuring was carried out in the next trimester for the same period of 30 (31) days. That means that the measuring was carried out four times per year.

Technological route in biogas plant

The biogas plant was originally designed for the maximal daily input materials batch of 250 $m^3.d^{-1}$. The facility comprises of a homogenization tank 300 m^3, sludge pit 100 m^3, two two-chamber fermenters with the overall capacity 5 000 m^3 (2 pieces × 2 500 m^3 = 5 000 m^3) with a mesophilic fermentation process between 37 and 42 °C, independent gas container 1 000 m^3, tanks for storing fermentation residue with a volume of 7 600 m^3 within the farm premises, storage tanks 5 000 m^3 + 1 800 m^3 outside the facility premises; the overall capacity of all storage premises is 14 400 m^3, an energy centre with 6 co-generation units with an overall electric output of 900 kW_{el}, including the emergency burner. The facility is a combination of electricity and heat production. The electricity is partly consumed in the farm. However, the largest proportion of energy is supplied to a central distributional system in accordance with the energy law. The heat produced is used during the biogas plant technological process, heating the supply water and the heating of the farm.

Monitoring biogas production dependent on the input substrate within the interval of 30 days – methods of evaluation of biogas plant operation within the course of the intensification and modernization of the fermentation process

The biogas plant operation was monitored at the defined interval of three months. The monitoring period was 30, or rather 31 days. Information about all input materials was recorded. The records started with the information of their weight and process technology and ended with the information of the final fermentation residue production. The same measuring was carried out in the next trimester for the same period of 30 (31) days. The measuring was carried out four times per year.

Technological route in biogas plant

The planned re-building lies in the second stage execution within the current biogas station and in extension of the storage tanks (2 × 5 000 m^3). A change in the current operation concept will change due to the scope of the planned building works. The biogas plant construction stems from time-proven technology of liquid substrates fermentation in the scope of the mesophilic process. The construction contains new fermentation residue storage houses with the capacity of approximately 2 × 5 000 m^3, integrated gas containers with the capacity of approximately 2 × 1 500 m^3, a fermentation residue transfer pit with the capacity of approximately 327 m^3, the input pit for substrates before the pasteurization with the capacity of approximately 20 m^3, a building for co-generation, a building for pasteurization and a place for tapping. Six co-generation units will be moved out of the current boiler room within the farm premises to a newly constructed building. Two new co-generation units will be constructed as containers and will be placed next to the new building. A heat distribution facility will be placed into the new building as well. The central control board will remain the same. The current biogas plant facility will be retained and will be further utilized in the first stage of fermentation.

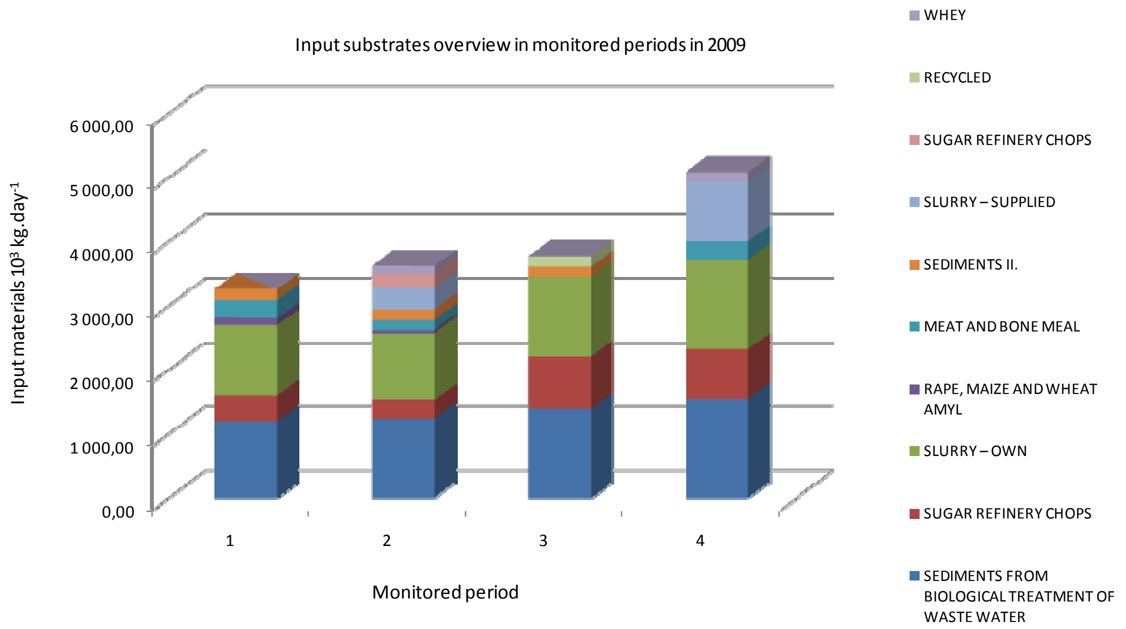
RESULTS AND DISCUSSION

Input substrates and electricity production before intensification and modernization of the fermentation process (2009)

All input substrates entering the fermentation process are stated in the chart and the graphical overview that follows. Chart II even contains sums of the input substrates according to the monitored period as well as according to the kinds of input substrates. In 2009, when the biogas plant was in full operation, the input substrates were of

II: *Input substrates overview in monitored periods in 2009*

Monitored period	Input materials 10^3 kg.day^{-1}										
	SEDIMENTS FROM BIOLOGICAL TREATMENT OF WASTE WATER	SUGAR REFINERY CHOPS	SLURRY – OWN	RAPE, MAIZE AND WHEAT AMYL	MEAT AND BONE MEAL	SEDIMENTS II.	SLURRY – SUPPLIED	SUGAR REFINERY CHOPS	RECYCLED	WHEY	TOTAL
I.	1 200,92	406,51	1 090	115,65	275,51	174,03	0	0	0	0	3 262,62
II.	1 234,94	295,95	1 040	54,77	151,78	164,67	330	226,72	0	120	3 618,83
III.	1 388,96	822,56	1 240	0	0	159,06	0	0	165	0	3 775,58
IV.	1 557,37	768,41	1 395	0	284,96	0	930	0	0	150	5 085,74
TOTAL	5 382,19	2 293,43	4 765,00	170,42	712,25	497,76	1 260,00	226,72	165,00	270,00	15 742,77



1: *Graphical overview of the individual input substrates ratio, in 10^3 kg.day^{-1}, in monitored periods of 2009*

heterogeneous character. Substrates from industrial production, meat and bone meal, sediments from biological treatment of waste water and other materials were accepted as the input substrates in addition to the basic substrates platform.

Plan of the electricity production and the actually achieved values are introduced in Chart III. The graphical overview illustrates higher values achieved during real operation in 2009.

Preliminary contracts with industrial waste producers, who granted the average substrate supplies, were the basis for compiling the electricity production plan for 2009. This plan was compiled by the experimental biogas plant management. Furthermore, slurry production and the slurry supplies from other pig-breeding increased in the fourth monitored period of 2009. This fact later became apparent on the electricity production.

Input substrates and electricity production after intensification and modernization of the fermentation process (2011).

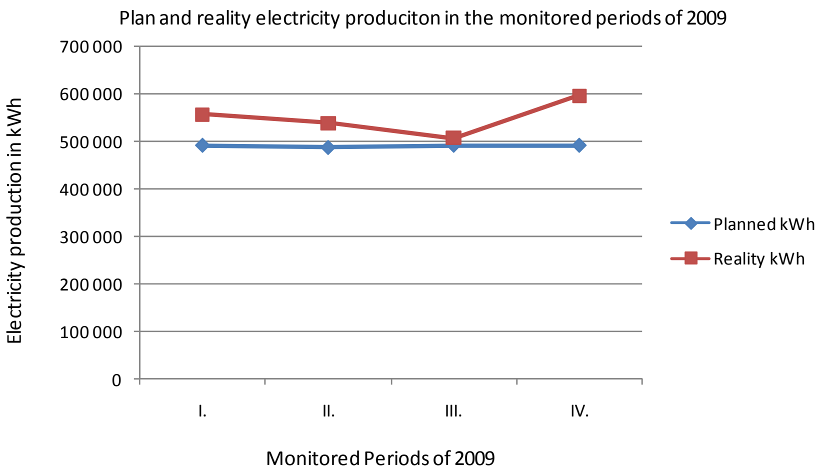
As was mentioned above, a delay in preparation works and re-building of the biogas plant occurred. The fermentation process entered the field test operation after the intensification and modernization of the whole process only in the second monitored period. The biogas plant was continuously in operation during the construction works and the fully functional fermentation process was gradually started. This occurred, as was assumed, while the intensification process was being planned. The system of accepting input materials is based on technological process modeling. The predominant input component must be taken into account so it is possible to point out the substrate with the highest biogas yield. Furthermore, it must be possible to implement the obtained data in other biogas plants in operation.

The fermentation process has now been started with an emphasis on the operation after the process was intensified. The input materials and fermentation process were monitored during first four months of 2011.

Chart IV, which follows, states the input substrates accepted in 2011. The same methods have been used as for the monitoring in the previously monitored year of 2009.

III: *Plan and reality in electricity production in the monitored periods of 2009*

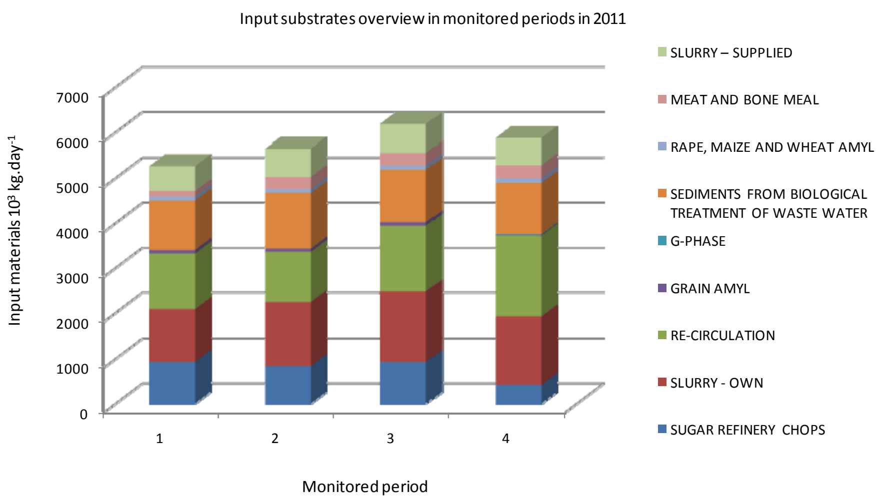
Period	Number of days in operation	Plan		Reality	
		kWh	%	kWh	%
I.	31	491 040	55	556 160	83.06
II.	30	486 327	55	538 115	83.04
III.	31	491 040	55	506 769	75.68
IV.	30	491 040	55	595 370	96.08



2: *Graphical illustration of plan and reality in electricity production during the monitored periods in 2009*

IV: *Input substrates overview in monitored periods of 2011*

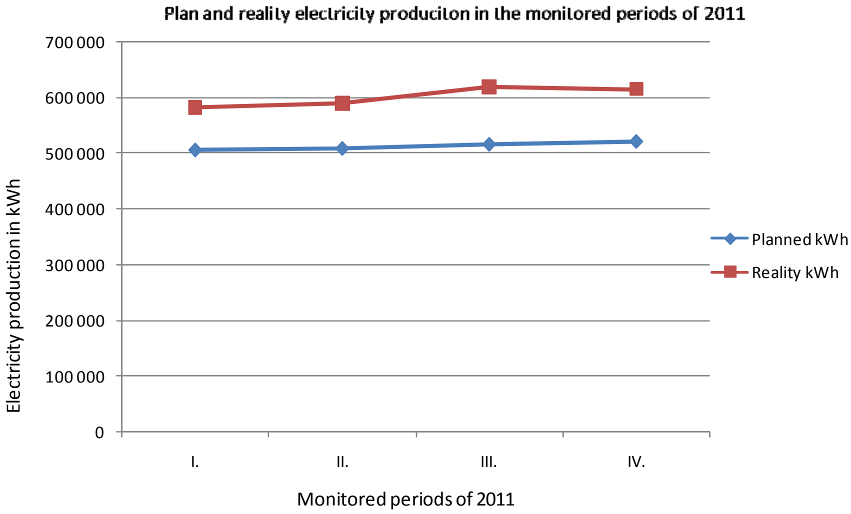
Monitored period	Input materials 10^3 kg.day^{-1}									
	SUGAR REFINERY CHOPS	SLURRY - OWN	RE-CIRCULATION	GRAIN AMYL	G-PHASE	SEDIMENTS FROM BIOLOGICAL TREATMENT OF WASTE WATER	RAPE, MAIZE AND WHEAT AMYL	MEAT AND BONE MEAL	SLURRY – SUPPLIED	TOTAL
I.	930	1 150	1240	77,5	0	1102	86,24	124,68	552,47	5 262,89
II.	840	1 400	1120	70	0	1241	84,62	268,57	621,14	5 645,33
III.	930	1 550	1460	77,5	0	1168	92,47	274,12	632,61	6 184,70
IV.	418	1 500	1800	17,5	16	1142	98,32	287,65	598,24	5 877,71
TOTAL	3 118,00	5 600,00	5 620,00	242,50	16,00	4 653,00	361,65	955,02	2 404,46	22 970,63



3: *Graphical overview of the individual input substrates ratio in individual monitored periods, in 10^3 kg.d^{-1}*

V: *Plan and reality in electricity production in 2011*

Period	Number of days in operation	Plan		Reality	
		kWh	%	kWh	%
I.	31	505 771	70	581 637	86.9
II.	25	508 464	70	589 818	109.2
III.	31	515 592	70	618 710	92.4
IV.	30	520 502	70	614 192	94.8



4: *Graphical illustration of plan and reality in electricity production during the monitored periods in 2011*

Suitable combinations of the primary substrates entering the biogas process have been adjusted on the basis of comparison of the input substrates, temperature, duration of the fermentation process and others. All of the procedures were carried out in such a way that they clearly convey the suitable composition of the input substrates. Their results may be implemented on other current anaerobic fermentation systems. During the first monitored period, part of the fermented substrate was still transported to another biogas station because of the building conversions which were taking place at the experimental biogas station. Nevertheless, a second stage of methanogenesis was also ensured by the subsequent application of the substrate into the fermentation process. However, the experimental biogas plant commenced the field test operation after intensification and modernization in the second, third and fourth monitored periods.

A gradual increase in electricity production occurred from the beginning of the monitored periods despite the fact that part of the fermented substrate was being transported to other biogas plants during the first measured period. This fact is proven by the graphical illustration (Fig. 4).

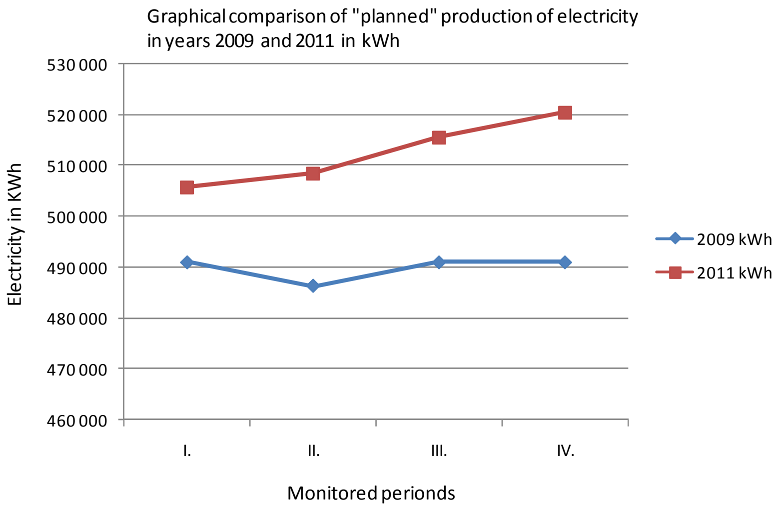
Comparison of years 2009 and 2011

An explicit connection between the values reached in electricity production and the accepted substrates exists as it is proven by the graphs.

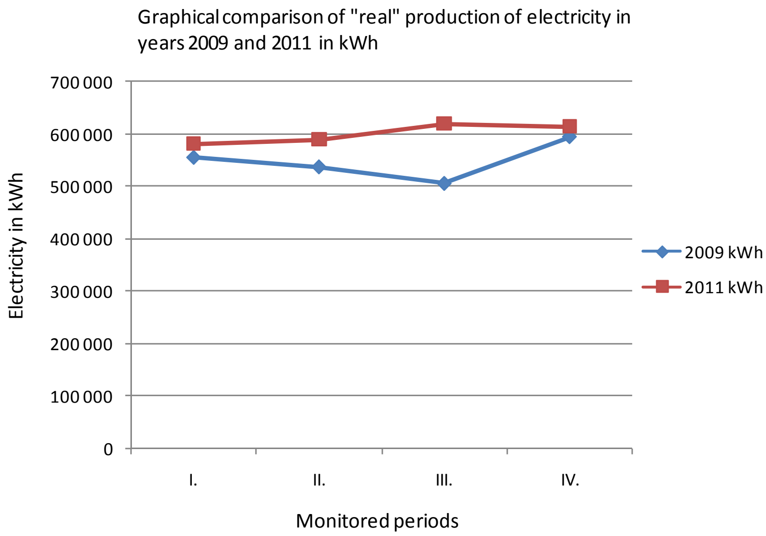
A gradual increase in electricity production was planned as may be seen in the graphical illustration of the planned production in the monitored periods. In reality the electricity production was not as rapid as planned, however, it is evident that the reality surpassed the planned values. The input substrates were batched in such a way that made provisions

VI: *Real amount of electricity produced in years 2009 and 2011; in kWh*

Real Electricity Production – Comparison of Amounts			
Period	2009	2011	Difference in %
	kWh	kWh	
I.	556 160	581 637	4.58
II.	538 115	589 818	9.61
III.	506 769	618 710	22.09
IV.	595 370	614 192	3.16



5: *Graphical comparison of "Planned" production of electricity in years 2009 and 2011, in* kW_h



6: *Graphical comparison of "Real" production of electricity in years 2009 and 2011, in* kW_h

for a longer period of the fermentation process, a higher biogas yield (or rather higher production of electricity) and a fermentation residue of higher quality (and thus a limitation of effluvium).

CONCLUSION

The anaerobic fermentation process has been a topic frequently dealt with in many discussions. The discussions may occur either between the experts as well as the biogas plant operators or laymen. The laymen evolve the discussions on the basis of publicly accessible information. The whole process of obtaining electricity is such a broad topic that new views of this kind of renewable energy sources and diverse opinions on technical and technological processes have been constantly springing up.

The topic of this work is to study biogas production, or rather electricity production in a precisely defined period; that is, in four monitored periods. Although the anaerobic process monitoring during the intensification and modernization of the experimental biogas plant took place with a two-year gap, it was carried out using the same methods including frequency of measuring. The amounts for the year 2011 are higher than for the year 2009 as shown in Fig. 6 (comparison of real electricity production in monitored periods of years 2009 and 2011). The amount is 8.16 % higher in the monitored period I, 9.16 % higher in the monitored period II, 22.09 % higher in the monitored period III and 3.16 % higher in the monitored period IV. Transport of the fermenter content to another biogas plant occurred in the first monitored period; the second stage of the fermentation process took place there. Gradual commencement of fermentation after intensification and modernization began in the second monitored period. The management counted an outstanding increase in biogas production as Fig. 5 proves (graphical illustration of the planned production of electricity). The increase was achieved mainly due to two fundamental points of the fermentation process intensification; a longer period of the fermentation process and the grinding and homogeneity of the input substrates.

An increase in the amount of hydrogen sulphide (H_2S) up to the degree when the material is not suitable as an input material for the co-fermentation appears during the co-fermentation of the input material combined with the meat and bone meal. The material with a high H_2S content is not suitable because of the high probability of corrosion in the co-generation unit. It was necessary to regulate additional access of oxygen from the air into the fermenter for desulphurization. The amount of oxygen had to be dosed in such a way that the biogas outgoing from the reactor did not contain any oxygen.

The fermentation residues from the second, third and fourth monitored periods also showed the benefits of the process intensification. The second stage of the fermentation process contributed to better stability of the output mass with a marked reduction of effluvium.

SUMMARY

Unfortunately, no direct description of methods or input materials which are used for the most effective process of anaerobic fermentation within depicted biogas plant has been found in the papers and articles on the anaerobic fermentation process which were previously published. This also applies to other published results which could be compared to our results regarding the input material of the fermentation process. Pulpous plants with a high content of nitrogen, for example helianthi, rape and maize, are the most frequently recommended for biogas production via co-fermentation (VÁŇA, 2009). The input substrates contain components which grant a high methane yield and thus a high electricity yield as is shown in Pic. 1 and Pic. 3 (input substrates in years 2009 and 2011). Literature claims that the highest biogas yield is obtained by the use of old grease, rape cake, food residues and slaughterhouse waste (FACHAGENTUR NACHWACHSENDE ROHSTOFFE, 2010). We still may only model suitable input substrates and their mutual batching as we are only at the beginning of the experimental biogas plant field test operation monitoring after intensification and modernization of the fermentation process. The electricity production will depend on the batching in the next monitored period. A gradual increase in electricity production occurs, more than anticipated as Fig. 4 shows. Thus, it may be predicted that this development will continue in biogas plant experimental operation.

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