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ANALYSIS OF SUBSTRATES FROM STARCH PRODUCTION IN CONNECTION WITH BIOMASS POWER PLANT DESIGNS

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Summary. An increase in demand for renewable energy sources resulting from a number of legislative orders gives rise to dynamic development of biogas production technologies. Properties of substrates suitable for anaerobic fermentation are tested by Mendel University in Brno which has built the "Biomass Transformation Reference Laboratory of the Republic" and that is where the university performs the tests. This laboratory is provided with reactors of various volumes controlling all the variables on which the course of the process, measurement of the quantity of the biogas being generated, temperature measurement, and openings for sampling the substrate and biogas depend. One group of tests was focused on waste produced by starch industry that can be used within the mesophyll anaerobic fermentation. Composition of the dosed substrate was as follows: pentose 22.57%, bran 22.57%, B-starch 4.07%, draff 5.64% and floater 45.15%. Tests were performed by means of co-fermentation with an inoculation substrate from an agricultural biomass power plant in 10 reactors of which 2 were kept without substrate additions. Biogas production out of these checked reactors was then subtracted from the total production of biogas out of the reactors with substrate. On the basis of the test results the average production of biogas or methane per one kilogram of dry matter respectively was calculated. Subsequently, on the basis of the production the biomass power plant was designed which is to become a part of the starch factory premises.

Key words: biomass, starch waste, methane yield

Introduction

Anaerobic digestion in biogas plants is very promising, because it can reduce methane emissions during uncontrolled biochemical processes associated with storage products and agricultural waste as manure or other waste of agricultural production [Szlachta 2009].

Construction of every biogas power plant requires that several principles should be followed. The very preparation activities as well as the construction activities must comply with a number of laws which apply to this process (air, fertilisers, energy industry...), and for that reason the very preparation steps, which are the corner stone of the following project, i.e. its economic efficiency, durability and utility, must be carefully considered and weighed up. During this preparatory stage it is necessary to communicate properly on a timely basis with authorities as well as to communicate openly with citizens who may be influenced by the project in any way.

Within the next step it is necessary to check and verify whether there is a sufficient number of inlet substrates and to ensure their regular and timely supplies. It is necessary to specify in advance what materials are to be processed, whether their sufficient supply will be provided and it is also necessary to prevent any considerable changes in the used substrate which could cause inhibition of the process in fermentors and the subsequent interruption in biogas production generation.

The third and very important factor of a smooth-running biomass power plant is to determine the biomass exploitability in connection with particular materials. The biogas production is mostly based on dry matter of particular substrates. It is also necessary to specify correctly the mixture to be used for co-fermentation with respect to its composition (amount of nitrogen, etc.), the dosed amount and its effect on the activities of anaerobic communities also with respect to the subsequent composition of the biogas being generated. Without reliable quantitative and qualitative properties of the substrates it is not even possible to propose any functional units of the biomass power plant to be designed, and for that reason this paper deals with the tests [Schulz 2004].

With respect to the fact that fermentation is a set of processes following one another, within which biologically degradable materials are transformed by means of microorganisms, it is necessary to set and maintain the conditions (oxygen, temperature, nutrients, pH, inhibiting substances, etc.) under which inhibition or interruption of activities of these microorganisms does not occur. There are a number of different techniques, which are usually distinguished on the basis of the operating temperature (i.e. thermophilic plants operate at around 55°C (50–65°C) and mesophilic ones at around 35°C (20–45°C) and the percentage of dry matter in the feedstock (i.e. dry systems with 30–40% dry matter, wet systems with 10–25% dry matter) [Karagianidis 2008].

Biomass power plants are associated with the use of the biomass energy potential. The most frequent biomass use is combined electricity and heat generation by means of units called cogeneration units. It is necessary to consider the number of cogeneration units to be purchased in order to ensure their reliable running, optimum biomass use and the associated service and inspections. By burning biomass in a cogeneration unit, in addition to electricity generation, (respectively more) heat is generated as well and its prospective use should be specified during the stage of the feasibility study.

After all these criteria are considered, it is inevitable that another output of the biomass power plant should be considered as well, this output is fermentation residue. The way of using it depends on particular conditions, however, quite often it is used as a fertiliser either for sale after registration or for one's own use.

Among the last principles are economic ones involving mostly capital costs and operating costs of optimisation.

A number of the biomass power plant projects have not been approved, put into effect or running properly which was caused mostly by the failure to follow some of these principles. The objective of the study herein, which comes before the construction of a new biomass power plant using starch waste which is analysed to a small extent as a substrate for this use, is to avoid these mistakes and errors.

Goal

The objective of the measurement was to determine the suitable use of the starch waste in biomass power plants for the purposes of their subsequent designing. The research was based on the determination of quantitative and qualitative parameters of biogas production from the given waste.

Material and method

The tests were performed in the Biomass Transformation Reference Laboratory of the Republic at Mendel University in Brno. 10 test reactors of the required volumes are also a part of the laboratory. The reactors are heated by means of a water bath and quantitative and qualitative measurements of the biogas being generated are taken every day. For the purposes of applying additives the reactors are equipped with a probe, a thermometer to take the substrate temperatures, openings to take substrate samples and to ensure biogas removal. The above named equipment was installed on the reactor so that the surrounding air cannot get into the reactor.

Substrate characteristics

The reactors were supplied with the substrate from the reactor of the agricultural biomass power plant in Čejč, processing a mixture of maize silage and semi-liquid manure. The substrate was taken in quantity sufficient to properly fill all the reactors in order to ensure identical initial conditions for all the tests. The substrate was placed into the reactors immediately after its transport so that its properties were changed as little as possible. The following table shows percentages of particular substances in the prepared mixture. The percentages are based on the expected daily dose of 88 600 kg of the starch waste.

Table 1. Composition of the tested substrate
Tabela 1. Skład badanych substratów

Substrate	Percentage [%]
Pentose	22.57
Bran	22.57
B-starch	4.07
Draff	5.64
Floater	45.15

Test procedure

Particular reactors were filled with inoculum and waste mixture, only two reactors were kept without the mixture as control ones. The tests were performed in accordance with standardised procedures for a period of 22 days under the conditions of anaerobic mesophyll fermentation (38°C).

Monitored parameters

Prior to the commencement of the test the following values were measured: pH, dry matter, combustible organic substances of the substrate from the biomass power plant and the tested mixture. Temperature in the reactors was maintained at the required value.

During the tests the following parameters were measured every day:

– total amount of the generated biogas by means of the water gasholder
– volume representation of chosen gases in the biogas (CH_4, CO_2, O_2, H_2 a' H_2S) by means of a BINDER instrument

After the test was completed, the following were determined: dry matter, combustible organic substances and pH.

Reactors kept only with inoculum were used as control ones and the average value of their biogas production were subtracted from the total production of every reactor. This way the real value of the biogas generated from the tested mixture was reached. The measurement results of the tested reactors were converted into the quantity of the dosed dry matter. Then it was possible to convert the acquired data into the corresponding biogas production for various sizes of the operating reactors of the biomass power plant.

Further tests required by the client were focused on the determination of CHSK, nitrogen and other substances in the fermentation residue. The determination was performed by the waste water treatment plant where the liquid digester will be supplied.

Description of the laboratory instrumentation and specification of the analysed parameters:

– BINDER gas flow indicator: measuring the biogas quality of CH_4, CO_2, H_2, H_2S, O_2
– BK G4 gas meter: measuring the quality of the biogas being generated
– LMH 07/12 muffle furnace: determination of dry matter and combustible organic substances
– RADWAG AS 220/C/2 laboratory balance: weighing the sample while determining the dry matter
– HACH-LANGE DR 2000 spectrophotometer: determination of CHSK, N, P, K, Na, S
– Magic gryf – measurement of pH XB-4-KS

Results

Tests took place repeatedly in 10 reactors of the volume of $3 \cdot 10^{-3}$ m^3, and the composition of the substrate has always been the same. The graphic representation of the results shows that the production of particular reactors do not show any significant deviations and therefore it is possible to say that the informative value of the test reached a very high level and the tested process of fermentation was stable all the time. The charts show average values of all repetitions of tests until the achievement of the required value of reliability level of 0.05. The charts show daily and cumulative productions of biogas and methane in relation to one kilo of dry matter. On the basis of the results and the subsequent conversion it is possible to determine the necessary size of the biomass power plant being designed.

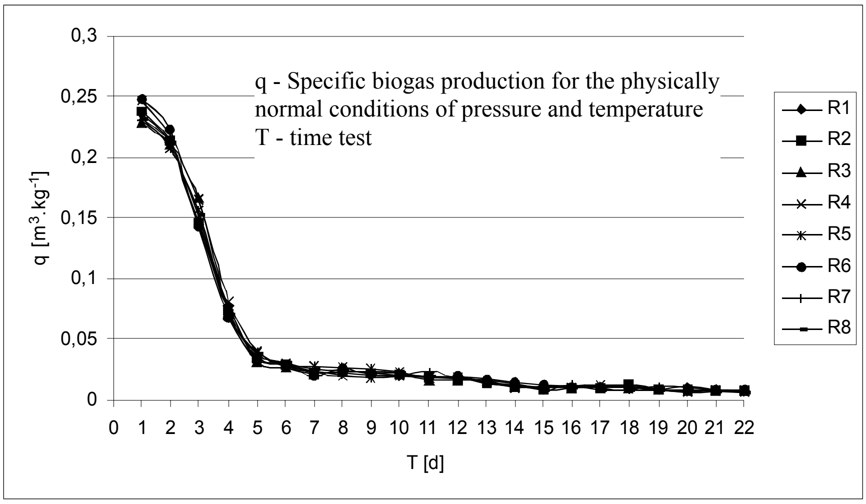

Fig. 1. Daily biogas production
Rys. 1 Dzienna produkcja biogazu

On the basis of the daily and cumulative biogas production it is clear that the highest values of the test were achieved during the first fifteen days. Stabilisation after the fifteenth day is caused by discontinuous technology which is characterised by consumption of organic substances, namely drop of the usable dry matter.

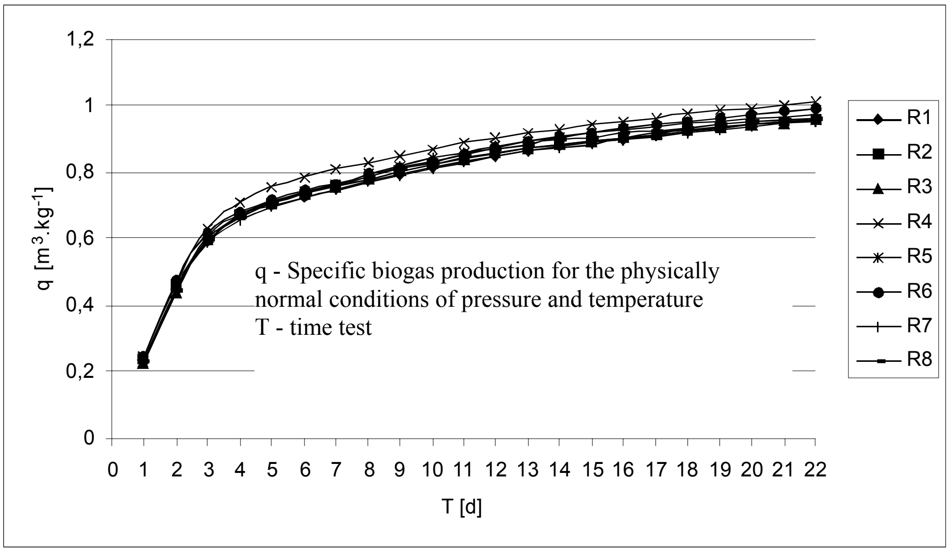

Fig. 2. Cumulative biogas production
Rys. 2. Skumulowana produkcja biogazu

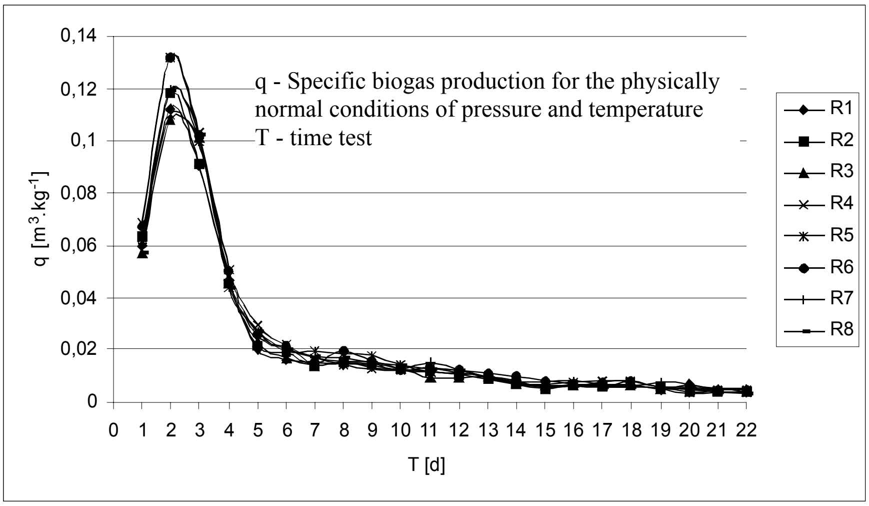

Fig. 3. Daily methane production
Rys. 3. Dzienna produkcja metanu

Methane is the main biogas component which participates in its calorific value and thus also the quality. That is why the biogas production is converted to pure methane so that the energy potential of the generated biogas is clear. As well as in the case of the biogas production the highest values are achieved by the 15th day.

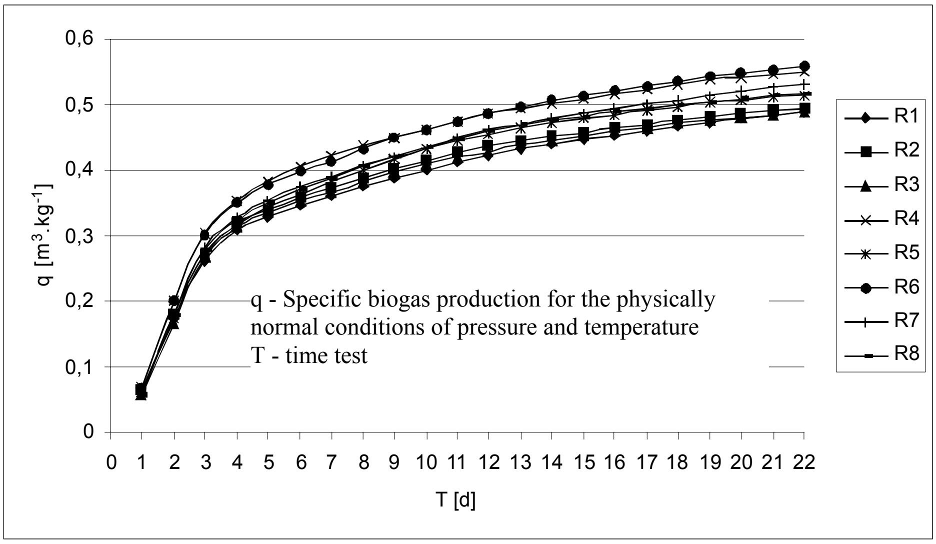

Fig. 4. Cumulative methane production
Rys. 4. Skumulowana produkcja metanu

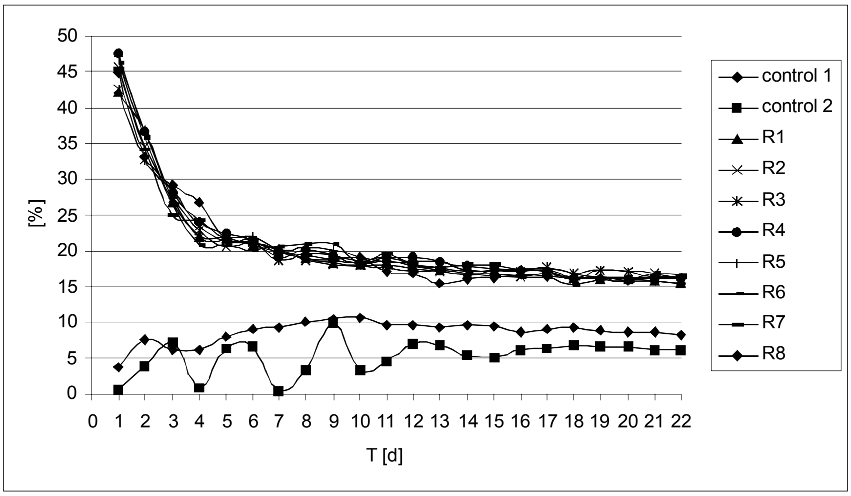

Fig. 5. CO_2 content in biogas
Rys. 5. Zawartość CO_2 w biogazie

At the beginning of the test the content of carbon dioxide in the biogas was very high. This is caused by the fact that immediately after the reactors are closed oxygen remains inside. First of all the aerobic degradation takes place and the main product of this degradation is carbon dioxide. After the oxygen was exhausted the processes were anaerobic and the content of carbon dioxide reached the average value of 15 to 20% of the volume.

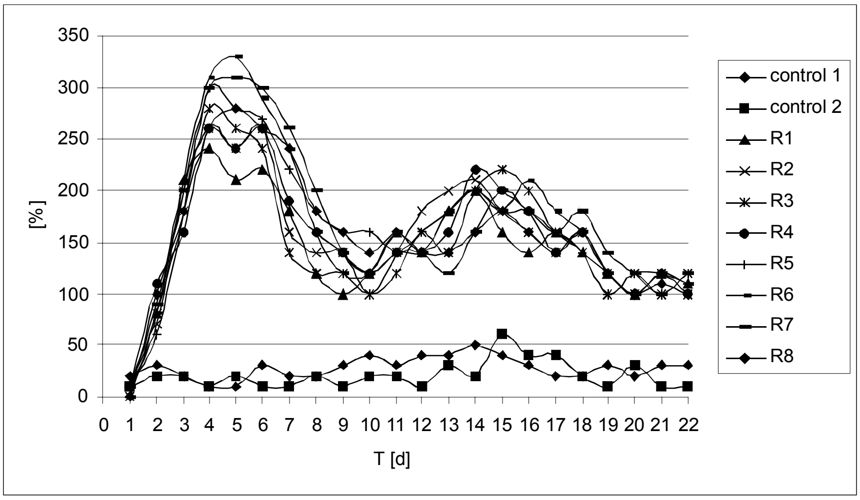

Fig. 6. H_2S content in biogas
Rys. 6. Zawartość H_2S w biogazie

Hydrogen sulphide is a toxic and highly reactive gas and therefore its presence in the biogas is undesirable as regards safety of operation and protection of equipment. Should the content of hydrogen sulphide be very high, it must be removed from the biogas. Hydrogen sulphide optimum concentration in the biogas as regards efficient operation of the biomass power plant up to 300 ppm. At the beginning of the test the measured values were considerably lower. This problem, however, may be disposed of by using continuous technology when the gas generated during different stages of degradation mixes and thus the hydrogen sulphide concentration gets lower.

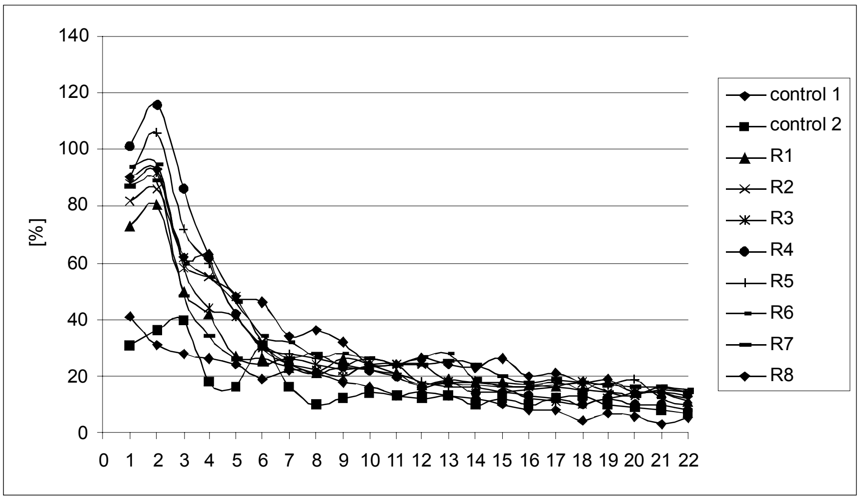

Fig. 7. H_2 content in biogas
Rys. 7. Zawartość H_2 w biogazie

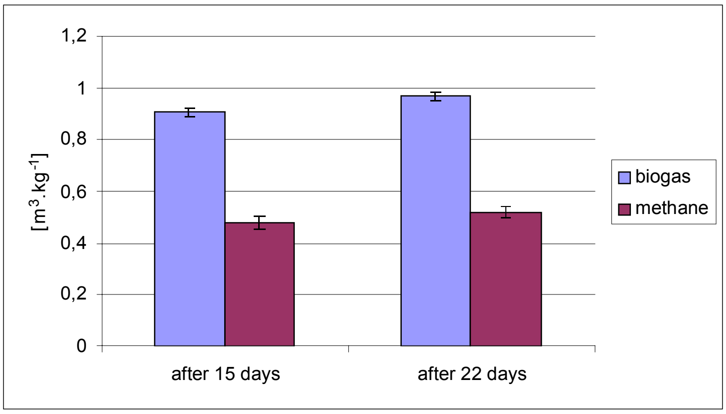

Fig. 8. Biogas and methane production
Rys. 8. Produkcja biogazu i metanu

Hydrogen is among the most sensitive indicators of process stability. It always signalises instability in the biogas. At the beginning its concentration was higher as a result of adding the substrate and burdening the system. Then the process was stabilised and the hydrogen concentration got lower.

Table 2. Methane and biogas production at the dose of 88 600 kg
Tabela 2. Produkcja metanu i biogazu przy dawce 88 600 kg

Dose of substrate	Biogas production after 15 days			
	Quantity of dry matter	Dose of dry matter	Unit production	Planned quantity
[kg]	[%]	[kg]	[$m^3.kg^{-1}$]	[m^3]
88 600	8.65	7663.9	0.9053	6938.13
Dose of substrate	Biogas production after 22 days			
	Quantity of dry matter	Dose of dry matter	Unit production	Planned quantity
[kg]	[%]	[kg]	[$m^3.kg^{-1}$]	[m^3]
88 600	8.65	7663.9	0.9708	7440.11
Dose of substrate	Methane production after 15 days			
	Quantity of dry matter	Dose of dry matter	Unit production	Planned quantity
[kg]	[%]	[kg]	[$m^3.kg^{-1}$]	[m^3]
88 600	8.65	7663.9	0.4779	3662.58
Dose of substrate	Methane production after 22 days			
	Quantity of dry matter	Dose of dry matter	Unit production	Planned quantity
[kg]	[%]	[kg]	[$m^3 \cdot kg^{-1}$]	[m^3]
88 600	8.65	7663.9	0.5176	3966.83

The dry matter of the starch waste mixture at the beginning of the test was 8.65% and the content of combustible substances was 95.78% of the dry matter.

Conclusion

On the basis of the results it is possible to say that the starch waste of the specified quantity and composition may be used as a substrate for a biomass power plant.

On the basis of the tests an average production of biogas per a kilogram of dry matter was calculated after fifteen days 0.9053 $m^3 \cdot kg^{-1}$ and 0.9708 $m^3 \cdot kg^{-1}$ after twenty-two days and 0.4779 $m^3 \cdot kg^{-1}$ methane after 15 days and 0.5176 $m^3 \cdot kg^{-1}$ after 22 days. Concluding, methane yield from energetic maize is between 0.312 and 0.365 $m^3 \cdot kg^{-1}$ [Amon 2007], 0.281–0.349 $m^3 \cdot kg^{-1}$ [Oslaj 2010].

The planned production at the residence time of 15 days would be 6938.13 m^3 of biogas, 3662.58 m^3 of methane and at 22 days the values would be 7440.11 m^3 of biogas and 3966.83 m^3 methane.

On the basis of the measured values the biomass power plant has been designed in two variants, however both of them expect the annually processed quantity of the inlet material of 153, 614 $t \cdot years^{-1}$, the annual quantity of biomass processed in the cogeneration unit 2, 208, 968 $m^3 \cdot year^{-1}$, the annual number of operating hours BPS: 8, 160 $hour \cdot year^{-1}$.

Variant I.

The biomass power plant will consist of an eco-Fermentor with an integrated gasholder and an IC reactor or an EGSB reactor. The facility capacity is optimised to the quantity of materials. This project involves construction of one reinforced concrete fermentor of the total volume of 2, 713 m^3, which will be roofed with a foil. In principle it is a round vertical tank, partly buried. A part of the biomass power plant will be a pre-tank and a storage tank for the fermentation residue. Materials will be added into the fermentor from the preparatory tank, which will be used for the first mixing of materials and for the purpose of their pumping the dry matter of the substrate will reach the value of some 10%. The tank will be made of concrete and buried. It will be provided with a propeller and paddle-wheel stirrer. The ceiling of the tank is also made of concrete, with an opening that may be closed and which will be used to fill the tank. From this place the material passes into the main, round, concrete, vertical fermentor, where the mesophyll fermentation will take place at the temperature of approx. 40°C. The fermentor will be heated on its inner wall and will be equipped with several high-speed propeller stirrers, whose height and directions can be adjusted and in addition to this they will be easily accessible in case of a defect. Assembly holes, openings to pump and dose the material will be further parts of the fermentor.

After fermentation the material passes from the fermentor into the storage tank for the purposes of temporary storing; the storage tank is a round reinforced concrete cast-in-situ structure. The main purpose is to balance the differences in volumes of the fermentation residue production and at the same time to ensure continuous supplying of the waste water treatment plant. Part of this tank is a control system regularly controlling the tank tightness and an optical monitoring and signalling equipment. In relation to the storage tank there will be the filling hard surface used as a pumping place for any possible emergency pumping of the tank outlet (for instance in case the waste water treatment plant is out of operation). The pumping area will be graded into the collecting shaft that will be drained right into the homogenisation tank.

As regards the generated biogas – from the gasholder it will be delivered by the gas pipes to the energy-use technology, and at the same time humidity will be removed and it will undergo desulphurisation. Then, the gas passes to the cogeneration unit engine.

The cogeneration unit and the entire engine-generator set incl. the above mentioned parts will be situated in a building made of cast-in-situ concrete. The whole unit will be provided with a noise cover, and a control panel. Biogas surplus will be burnt on a safety burner, in case the cogeneration is stopped or a sudden surplus occurs.

The result of the entire process, namely thermal energy and electrical energy, will be used right within the premises both in connection with this variant and in connection with the other variant. Only 5% of the electrical energy will be distributed into the network.

The thermal energy will be used within the biomass power plant for fermentation or heating of the substrate and for cooling cogeneration units. The secondary circuit provides water of 90°C which must be unconditionally cooled within the circulation to 70°C. The heat of the secondary circuit may further be used in heating systems.

The cogeneration unit consists of a generator producing electricity and driven by an internal combustion engine. In this case two cogeneration units of the total electrical output: 650 kW will be installed.

This variant will use an IC reactor or EGSB. The fermentation residue with organic substances will flow from the equalising and acidification tank through the mix-tank into the lower part of an anaerobic IC or EGSB reactor. The anaerobic reactor will convert the remaining organic substances into biogas. The biogas will be than processed in the biomass power plant.

Variant II.

On the basis of the submitted background documents on materials, the second variant is proposed with the use of two reinforced concrete fermentors which will be covered with a gas-tight cover and the biogas will be delivered from the dome of the gasholder by means of gas pipes. Part of the delivery of biogas into the cogeneration unit is the process of its drying and desulphurisation. External sides of the fermentor will be insulated with a contact warming-up system and clad with visual sheet (in vertical direction). Fermentors may be buried completely or partially. The process is the same as in the previous variant - mesophyll.

The material passes from the dosing equipment into fermentor I, where biogas is generated and then is pumped into fermentor II, where the fermentation residue is stabilised and further methane is generated. The fermentation residue then passes into the storage tank as a stabilised product without any further biogas generation and subsequently it is delivered to the local waste water treatment plant.

The cogeneration unit will have the same measures as are those in Variant I. It will be provided with a control panel. Surpluses will be stored in the domes of the integrated gasholder and should the domes be filled, it will be burnt by a flare stack which is situated safely away from the building of the biomass power plant. The other conditions are the same or similar to those of Variant I.

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ANALIZA SUBSTRATÓW POCHODZĄCYCH Z PRODUKCJI SKROBI W ZWIĄZKU Z PROJEKTAMI ELEKTROWNI BIOMASY

Streszczenie. Wzrost zapotrzebowania na odnawialne źródła energii, wynikający z licznych rozporządzeń legislacyjnych przyczynia się do dynamicznego rozwoju technologii produkcji biogazu. Właściwości substratów odpowiednich dla fermentacji beztlenowej badane są na Uniwersytecie Mendla w Brnie, gdzie wybudowano „Laboratorium Referencyjne Konwersji Biomasy” i gdzie przeprowadzane są badania. To laboratorium posiada reaktory o różnych wielkościach kontrolujące wszystkie zmienne, od których zależy proces, pomiary ilości wyprodukowanego biogazu, pomiary temperatury oraz otwory do umieszczania substratów. Jedna grupa badań skupiła się na odpadach pochodzących z przemysłu skrobiowego, które można zastosować do beztlenowej fermentacji mezofilicznej. Skład dozowanego substratu był następujący: pentoza – 22,57%, otręby – 22,57%, skrobia – 4.07%, wysłodki – 5.64% oraz osady – 45.15%. Badania przeprowadzono za pomocą k fermentacji z substratem do wysiewania bakterii pochodzącym z elektrowni biomasy rolniczej w 10 reaktorach, z których 2 utrzymywano bez dodatku substratów. Następnie odjęto produkcję biogazu pochodzącą z badanych reaktorów od całej produkcji biogazu z tych reaktorów lub obliczono ilość metanu na jeden kilogram suchej masy. Następnie, na podstawie produkcji wykonano projekt elektrowni biomasy, która ma stać się częścią budynków fabryki skrobi.

Słowa kluczowe: biomasa odpady skrobiowe, uzysk metanu

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