Biogas production through anaerobic fermentation, based on different waste biomass

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Abstract: - The paper presents a comparative experimental analysis between different types of biomass residues used for biogas production, during their behavior along the anaerobic fermentation process. The comparison is achieved using as parameter the biogas quality and quantity which are produced, using different available agricultural and wood residues: beech dust, linden dust, corn waste and a mixture composed by corn and mix of maize and corn waste. All the measurements were made on a lab scale pilot installation.

Key-Words: - biomass residues, anaerobic fermentation, pilot installation, biogas, RES

1 Introduction

Global supply of energy is facing several increasing challenges. Energy consumption is on a moderate increase, especially in rapidly developing countries. The overall size of the world energy market nearly doubled between 1971 and 2003, driven by rapid expansion in energy use in the developing world, where population and energy activity have grown. The International Energy Agency (IEA) has projected an increase in primary energy demand of 1.6 per cent per year until 2030, when the cumulative increase will be equal to half of current demand [1].

With exception of hydroelectricity and nuclear energy, the major part of all energy is produced from petroleum, charcoal and natural gas. However, these sources are limited, and will be exhausted by the end of this century [2]

Analyzing the existing estimates, it is noted that very short time remaining until the exhaustion of existing resources, at least for oil and natural gas, require the finding of immediate and efficient solutions to replace of energy witch will be produced, until than using these fuels. These solutions are all more necessary as energy consumption for the world economy are growing and it is not expected a reduction of this consumption in the near future. To solve this problem, the only foreseeable solution is the use of renewable energy.

Another major problem, the production of energy from conventional fuels, is the high level of CO_2 emissions (Figure 1), due process of energy production. These emissions contribute to accentuation greenhouse effect and accelerating climate change related phenomenon [3].

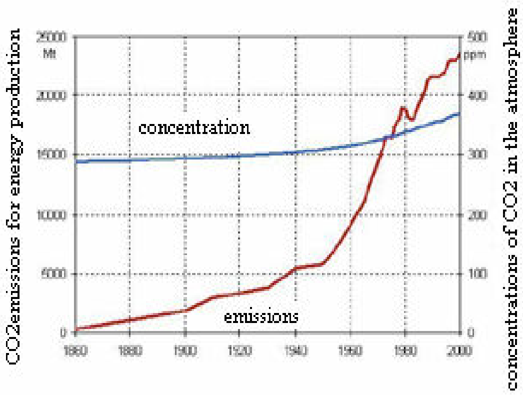

Fig. 1 - The level of CO_2 emissions in the atmosphere [3]

During the recent time period biomass resources' importance has increased enormously in the frame of energy systems. This is not only based on the current development of growth of public environmental awareness and their outer appearance but also on the fact that the biomass energy is the only renewable energy achieving continuous power as a result of planning and storing the available energy resource [4].

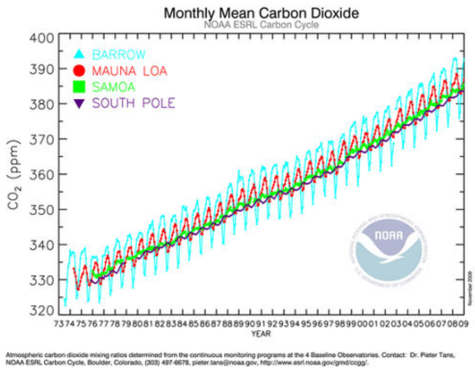

Fig. 2 – CO_2 annual emission determined at four Baseline Observatories [5]

The continuous growth in concentration for CO_2, determined at different observatories over time (Figure 2) represents a great problem which has to be addresses accordingly, using renewable sources of energy and clean technologies.

The use of biomass has for millennia helped human society to fulfill many of its fundamental energy needs, such as for the production of goods, cooking, domestic heating and the transport of people and goods [3]. Agricultural biomass production is generally considered to have the greatest energy potential of the three main biomass sources (agriculture, forests and waste). With current technologies, biomass from agriculture can satisfy a wider range of demands [6].

Agricultural waste is the second most common form of waste and includes waste from the raising of animals and the harvesting and processing of crops and trees. Other wastes associated with agriculture, such as waste from processing operations (peelings, seeds, straw, stems, sludge, and similar materials). Since most agricultural waste is organic, it is used as fertilizer or for other soil-enhancement activities [7].

One of the technologies used for energy recovery from biomass residues is the production of biogas through anaerobic fermentation. It is considered a RES (renewable energy resource) technology.

Anaerobic digestion and biogas production are promising means of achieving multiple environmental benefits and producing an energy carrier from renewable resources. Replacing fossil fuels with biogas normally reduces the emission not only of greenhouse gases, but also of nitrogen oxides, hydrocarbons, and particles [8].

Biogas could become one of the most important alternative fuels and can potentially replace natural gas and oil as it can contribute to maintain mobility, while other alternative sources of electrical energy and heat generation are available (wind, solar energy, etc.). No negative or limited environmental side effects are observed because biogas can be produced from all types of "green" biomass [9].

Related to the renewable sources influence inside the European Community, Table 1 indicates the share of renewable resources at the level of the year 2000.

Table 1, Share of renewable resources in European Union [10]

Energy source	Energetic share [%]
Coal	15
Oil	41
Natural Gas	23
Nuclear	15
Renewable	6

Fig. 2 presents, in connection with the allocation of biomass residues at Romanian level, the energetic potential related with biomass distribution in the different regions of the country.

Fig. 3 - Energy potential allocation in Romania [11]

Natural resources represent an essential part of Romania's richness and the exploitation of these resources, both renewable and non-renewable raw material, determines the social and economic development of the country, environmental status and living conditions of the population. In order to contribute to the quality of life in Romania, natural resources need to be exploited in a sustainable development manner. This mission is to find ways to increase the total wealth at the same time with prudently use of natural resources, so as the renewable sources to be maintained and nonrenewable sources to be used taking into account the needs of future generation [12].

Biogas from biomass represents one of the technologies which are evolving in Romania in present times. Because of this, different steps are taken in order to study ways and biomass types useful to produce biogas with good quality and in large quantities.

At the Unconventional Energies Laboratory of the Mechanical Engineering Faculty there was developed a pilot installation dedicated to the study of the behavior for different biomass residues.

2 Comparison between analytical and experimental methods used for studying the process of biogas production through anaerobic fermentation

Experts agree that Methanogenesis of biomass slurries has enormous potential, but to realize it will require improving the reaction rate and mass conversion efficiency.

The degree of mass conversion achievable in AD (anaerobic digestion) is directly proportional to the solids retention time (SRT) and inversely proportional to the fraction of non-biodegradable mass (R). The substrate refractory fraction varies greatly depending on its specific characteristics and history.

Complex long chain biopolymers like cellulose and lignin are major contributors to the non-biodegradable fraction (R) that severely limits the extent of Methanogenesis in conventional AD systems [13].

Monod model

The Monod model is proposed to be used in case of analytical approach of the biogas production through anaerobic fermentation, in order to realize a connection to the experimental. The method calculates the rates of substrate consumption, biomass growth, and product formation, meaning the main parameters of the process input and development. In this particular case presented one used as primary energy input different sorts of vegetal biomass, as typical for the plain region from Western part of Romania.

Based on Monod kinetics [14], the rate of substrate consumption (RS,R), biomass growth (RX,R), and product formation (RM,R) per unit of volume reactor in a batch reactor may be described by the equations (1), (2), and (3):

$$R_{S,R} = -\left(\frac{\mu^{\max}}{Y_{XS}} + M_s\right)\cdot\left(\frac{C_{S,R}}{C_{S,R}+K_S}\right)\cdot C_{X,R} \qquad (1)$$

$$R_{X,R} = \left\{\mu^{\max}\cdot\frac{C_{S,R}}{C_{S,R}+K_S} - M_S\cdot Y_{XS}\cdot\left(1-\frac{C_{S,R}}{C_{S,R}+K_S}\right)\right\}\cdot C_{X,R} \qquad (2)$$

$$R_{M,R} = -R_{S,R} - \mu^{\max}\cdot\frac{C_{S,R}}{C_{S,R}+K_S}\cdot C_{X,R} \qquad (3)$$

where: μ^{max} is the maximum growth rate,
K_S - the Monod half-saturation constant,
M_s - the maintenance coefficient,
Y_{XS} - the biomass yield,
$C_{S,R}$, $C_{X,R}$ - stand for the substrate, and biomass concentration in the reactor.

By combining these kinetic equations with mass balances for acetate conversion, the differential equations are derived. These equations can be integrated further, by using a fourth-order Runge-Kutta algorithm with adaptive step-size control [15].

The K_S value, and the initial substrate $C_{S,R}(0)$ and biomass concentrations $C_{X,R}(0)$ were estimated for each substrate feeding by minimizing the absolute error between measured and calculated values of the methane production rate. The estimated final biomass concentration from the previous feed was used as input value for the computations of the next feed. The parameter K_S , initial values $C_{S,R}$ (0) and $C_{X,R}$ (0) are strongly independent, therefore they can readily be estimated in a single optimization procedure. The K_S value is strictly related to the transition period in the methane production rate curve, the $C_{S,R}$ (0)-values are only dependent on the final cumulative amount of methane measured, and the $C_{X,R}$ (0)-is strictly dependent on the initial methane production rate [14].

The data were collected during the experimental measurements conducted on one pilot installation in order to be used for further calculations using the MONOD model.

Pilot installation description and functioning

The pilot installation is composed by the following systems:

- *preliminary preparation of biomass system*, with role to homogenize the material which will be inserted inside the anaerobic fermentation tanks, with the help of a submersible pump,
- *two anaerobic fermentation tanks,* used for depositing the suspension from which it will result biogas of quality and quantity

connected with the used material for the batch,
- *biogas evacuation system*, composed by polypropylene pipes and four electric valves, which are set to release the biogas produced inside the anaerobic fermentation tanks, when the pressure inside the tanks reaches a certain value controlled by the user. For small biogas quantities, the installation is equipped with a small tank placed on the upper part. The collected biogas can be used, and also analysis concerning its characteristics may be accomplished,
- *heating system*, composed by a small natural gas fuelled boiler and water pipes, destined to assure the desired level of temperature inside the anaerobic fermentation tanks; one notes that solar energy might be also used
- *biogas purification system,* composed by two filters, one for retaining the traces of H_2S (hydrogen sulfide) and one used for CO_2 retention. The role of the purification system is to assure a good quality biogas production,
- *CO_2 retention system*, composed by a stainless steel tank, a liquid separator and a buffer vessel, from which the exhaust gas is sucked by a compressor, at a pressure between 1 and 6 bar; it is placed inside a cylinder, at a pressure between 10 and 26 bar.
- *sensors and controllers,* which are connected with a command panel placed at the back of the pilot installation.

Details are also presented in [9] and [14].

The main purpose of pilot solution is to verify in a representative amount the energy transformations and balance in the case of the biogas production from waste products. The pilot is automatic controlled for the main parameters of the anaerobic fermentation process (temperature, pH and pressure).

Figure 3 presents the pilot installation schematics.

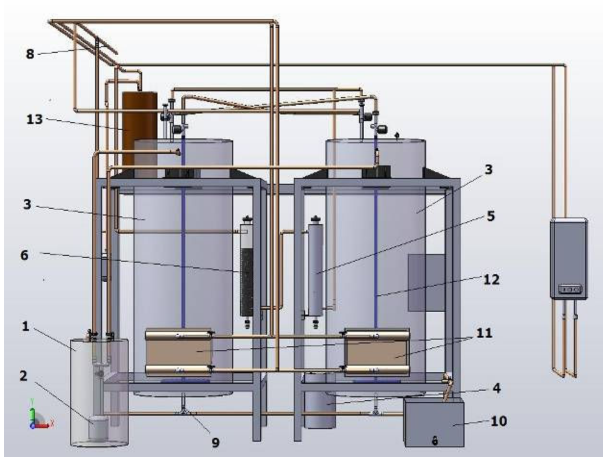

Fig. 4 - Pilot installation schematics [16]

1 – preparation tank, 2 – pump, 3 – fermentation reactors, 4 – correction agent tank, 5 - filter for retaining the H_2S, 6 - system used for retaining CO_2. 7 - adjacent system for CO_2 desorbtion and compression, 8 – consumer , 9 - gravimetric system, 10 – system for neutralizing the resulting liquid,11 – heating system, 12 - bubbling system,13 – tank for biogas samples.

From the biomass deposit, the used material is passed through a mill, and then it's sent to the tank where the preparation of the suspension of biomass is made (1). The biomass suspension is transported by means of the pump (2), and introduced into the fermentation reactors (3). The correction agent tank for the pH value assures, through the control system, the conditions for the process of anaerobic fermentation. The resulted biogas is passed through a filter for retaining the H_2S (5). Passing through a desorbtion system the CO_2 is retained up to 90 % by volume (6), thus the quality of the biogas is considerably improved. Further, its compression in the adjacent system (7) occurs. Finally the purified biogas is sent to a consumer (8) or evacuated in vessels or appropriate structure, as it is possible. The used material is discharged through the means of a gravimetric system (9), and the solid material is retained for being dried, using normally the natural drying. Following it is sent to a compost deposit for being used as a soil fertilizer. The compost is also a very good combustion matter, subject to new energy recovery. A part of the resulting liquid is neutralized in same cases in the system (10) and sent to the sewerage network or, in other schemes, it is transported by the recirculation pump (2) from the suspension preparation tank (1). The fermentation reactors are heated with thermostatic control, by using energy delivered from the system (11). For the homogenization of the suspension one uses a bubbling system (12), realized from polypropylene pipes, in order to avoid the possible corrosion. Also, for depositing small quantities of biogas of the purpose of analyzing, the installation is equipped with a small tank (13) positioned at the top of the reservoirs.

Based on the described pilot experimental analysis, related to biogas quality and quantity, using different sorts of wood and agricultural biomass residues, were accomplished.

Figures 4, 5, 6 and 7 present the biomass residues used for the experimental determinations. It results from a quick visual analysis that the fuel is grinded, uniform, quite fine distributed concerning the medium size of particles. One used two different types of agricultural biomass residues for experiments: agricultural and wood. One stresses that all the input materials are not taken from the food chain; they represent wastes, or non quality agricultural products. The measured values for each batch involved mainly the methane and carbon dioxide present in the obtained biogas.

Fig. 5 - Grains of corn Waste [16]

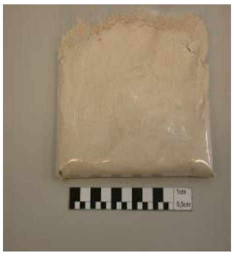
Fig. 6 - Mix of maize and corn waste [16]

Fig. 7 - Beech dust [16]


Fig. 8 - Linden dust [16]

3 Experimental and discussion

For each batch measurements were accomplished, in order to determine both quality and quantity of the obtained biogas and mainly its composition, in correlation to thermodynamic parameters installed. Also, analysis connected with main characteristics of the material which is used, before and after the use of the batches inside the anaerobic fermentation reactors, are completed.

In Table 2 the authors underline some of the main characteristics of the used material for the four batches (hygroscopic humidity, ash content, high calorific values, low calorific values), before the process of anaerobic fermentation is started. As it can be observed by analyzing the resulted figures, the high and low calorific values for the beech dust and linden dust batches are higher than those of the corn waste and the mix of corn and grain waste batches. The explanation is connected to the initial H and C content.

The duration of anaerobic fermentation: the process was 83 days for beech dust batch, 84 days for linden dust batch, 67 days for the mix of corn and grain waste batch and 83 days for the grains of corn waste batch. These durations experimentally proved were completely monitored.

The main parameters that were registered are: temperature, pH and pressure variation, for each separate batch, in real time. The instruments used were calibrated and standard methods were applied.

Table 2, Characteristics of the materials contained inside the used batches [16]

No	Sample	Hygroscopic humidity [%] by mass	Ash content [%] by mass	Low calorific value [kJ/kg]
1	Grains of corn waste	1.50	1.88	14488
2	Beech dust	0.51	0.92	16322
3	Linden dust	0.23	0.54	16263
4	Mix of maize and corn waste	0.88	1.64	15245

The resulted values underline the variation of these parameters for each batch, in dependence and correlated with the production (quantity and pressure) of biogas.

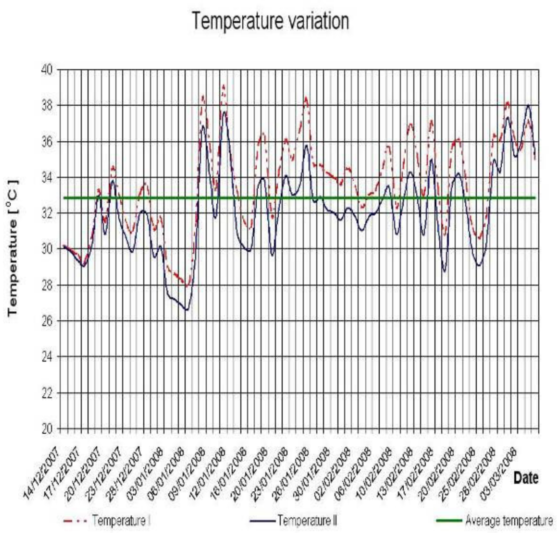

Fig. 9 – Time dependence of temperature variation – beech dust batch [16]

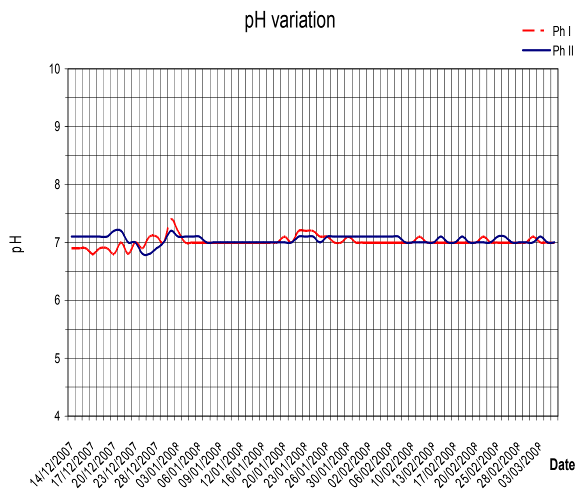

Fig. 10 – Time dependence of pH variation – beech dust batch [16]

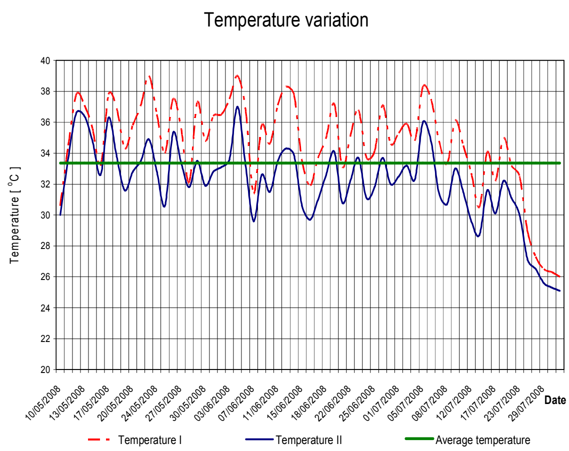

Fig. 11 – Time dependence of temperature variation – linden dust batch [16]

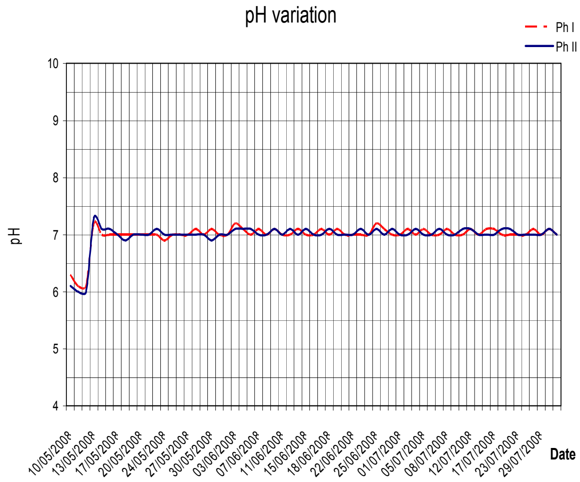

Fig. 12 – Time dependence of pH variation – linden dust batch [16]

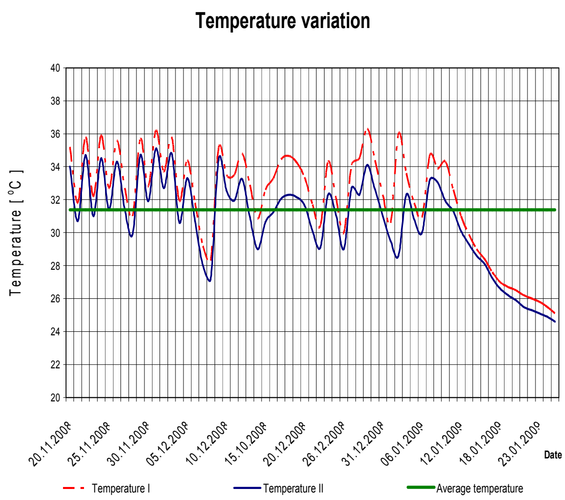

Fig. 13 - Time dependence of temperature variation – mix of corn and grain waste batch [16]

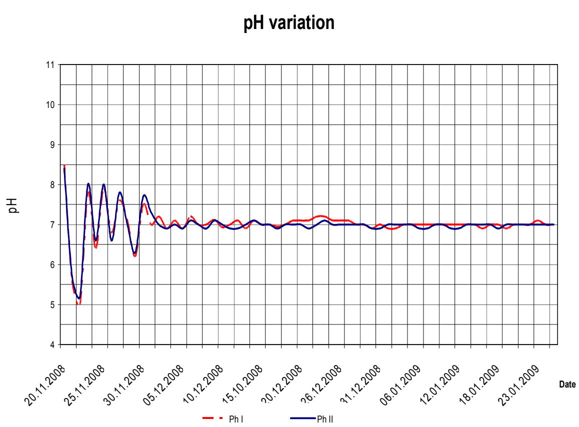

Fig. 14 – Time dependence of pH variation – mix of corn and grain waste batch [16]

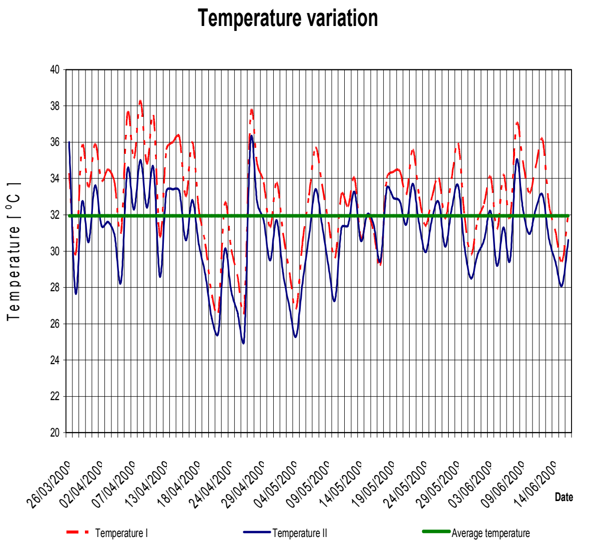

Fig. 15 – Time dependence of temperature variation – grains of corn waste batch [16]

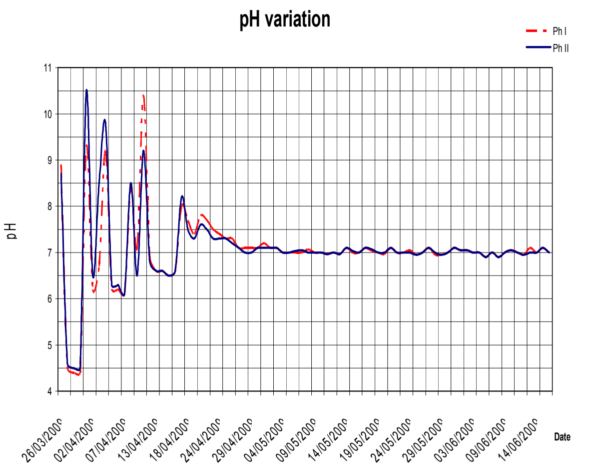

Fig. 16 – Time dependence of pH variation – grains of corn waste batch [16]

The temperature regime between 30 – 38 °C covers the mesophilic regime. The pH was maintained at a value between 7 - 7.5, in order to avoid the negative influence of the process of corrosion on the pilot installation material.

In Figures 16 to 23 the dependences between the pressure values obtained for each batch and the biogas production, in each case, are presented.

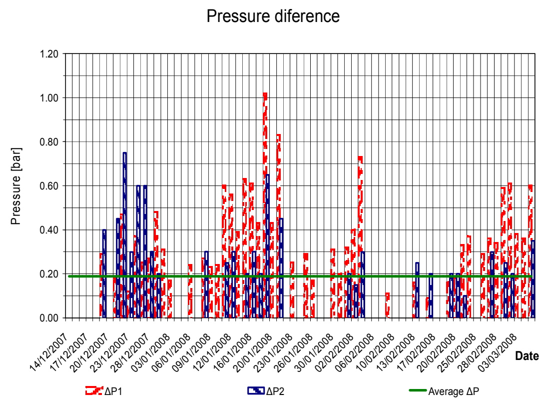

Fig. 17 – Time dependence of pressure difference for beech dust batch [16]

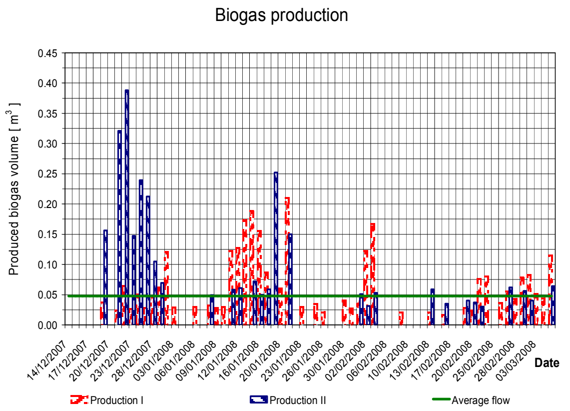

Fig. 18 – Time dependence for biogas production - beech dust batch [16]

From Figures 16 and 17 it results that the average value for the pressure difference is approx. 0.2 bars, and the biogas quantity is under 0.05 m^3 / day, values that are reasonable and expected, in connection to other standard applications.

In order to verify other types of wood material, further experiments, using linden dust, were planned. The results are presented in Figures 18 and 19.

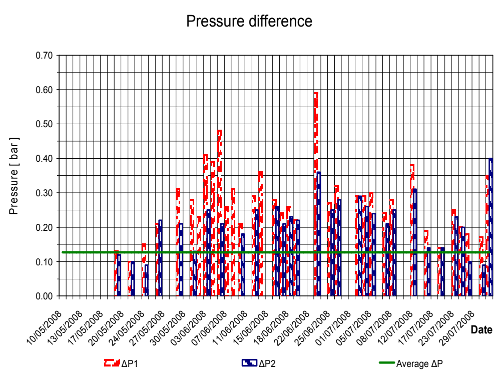

Fig. 19 – Time dependence for pressure difference - linden dust batch [16]

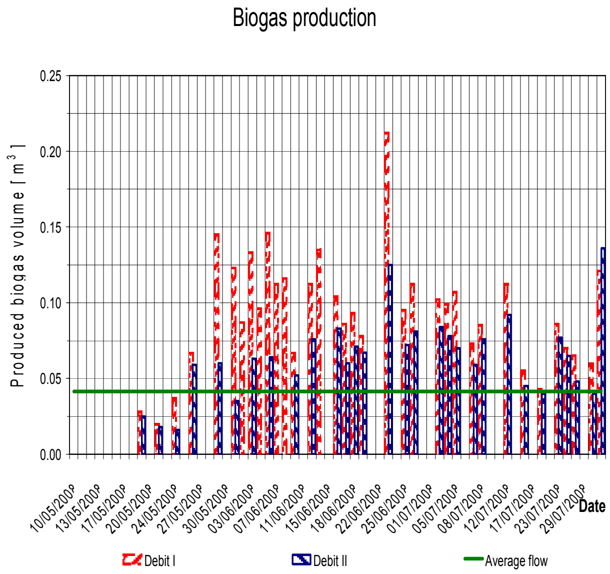

Fig. 20 – Time dependence for biogas production - linden dust batch [16]

The dependence between the pressure difference and the biogas production is at a low value, of 0.12 bar, meaning an equivalent biogas production of under 0.05 m^3/day, considering a daily temperature value of 34 º C.

A further range of experiments was based on agricultural waste: a mix of maize and corn waste. The results are presented in Figures 20 and 21.

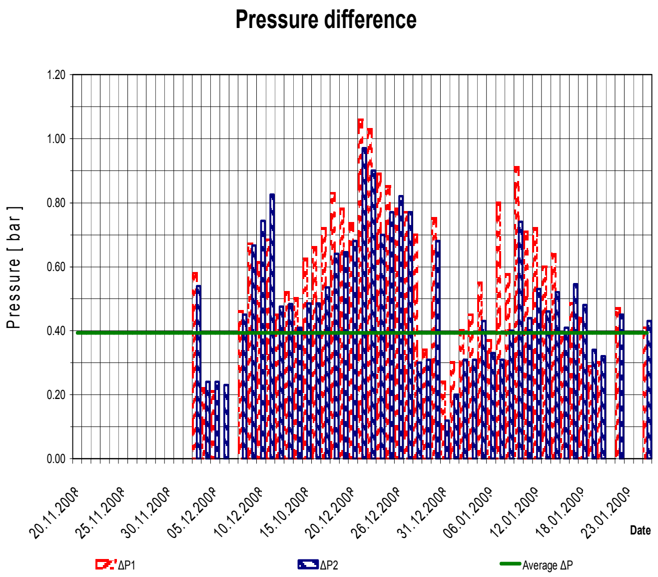

Fig. 21 – Time dependence for pressure difference - mix of maize and corn waste batch [16]

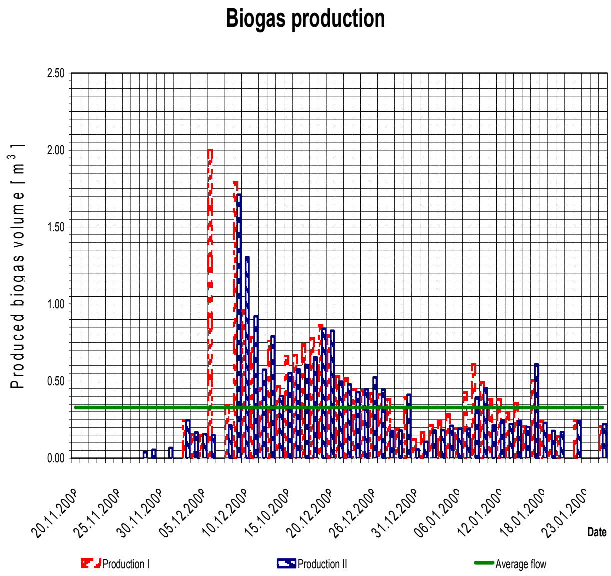

Fig. 22 – Time dependence for biogas production - mix of maize and corn waste batch [16]

From the comparative examination between the pressure difference and the biogas production, one observes that the average value is about 0.4 bars and the biogas production has peaks at 2 m^3, with an average value for production of 0.25 m^3 / day, for an average daily temperature value of 35 º C.

The last batch was composed only from grains of corn waste, and the results are presented in Figures 22 and 23.

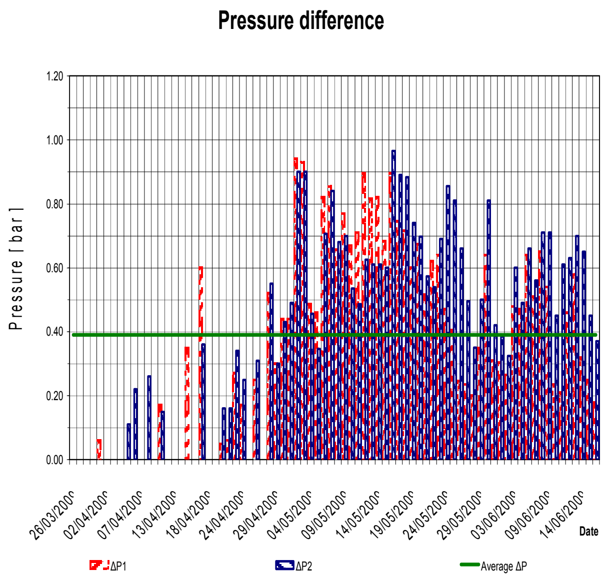

Fig. 23 – Time dependence for pressure difference - grains of corn waste batch [16]

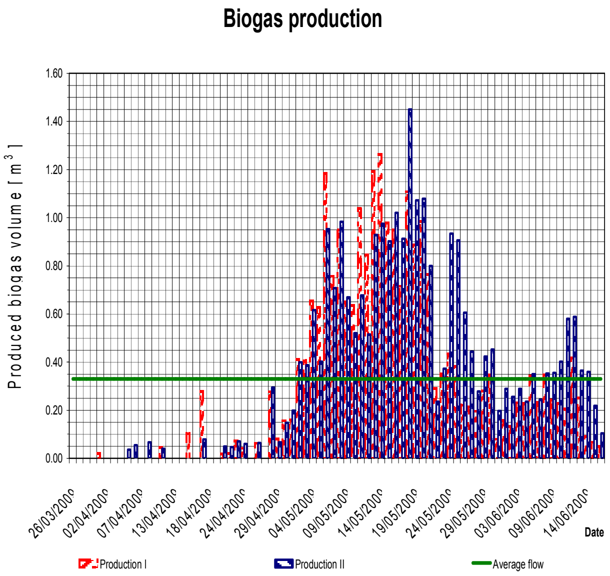

Fig. 24 – Time dependence for biogas production - grains of corn waste batch [16]

The correspondence between the pressure difference and the realized biogas production shows that this peculiar batch has produced the largest quantity of biogas from all the analyzed batches.

The comparison between the four ranges of experiments, in terms of quantities of produced biogas, is showed in Figure 24.

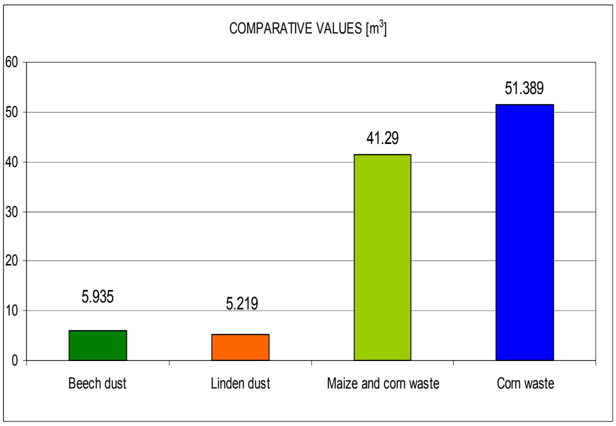

Fig. 25 - Comparative results regarding the biogas production [16]

In order to determine the percentage of methane and carbon dioxide concentrations mainly, in addition to other species, on line measurements during the anaerobic fermentation process were organized, involving three process intervals. Thus, one revealed that the initial period, after the Oxygen consumption, is characterized by the starting of the formation of the anaerobic bacteria. The second interval consists of the period with the maximum production of biogas, presented as a peak, in all diagrams. The last period reveals that the process is slowing down. The concentrations of methane and carbon dioxide are presented for each batch, meaning each reservoir, during the period with the maximum production of biogas (Figures 25 and 26).

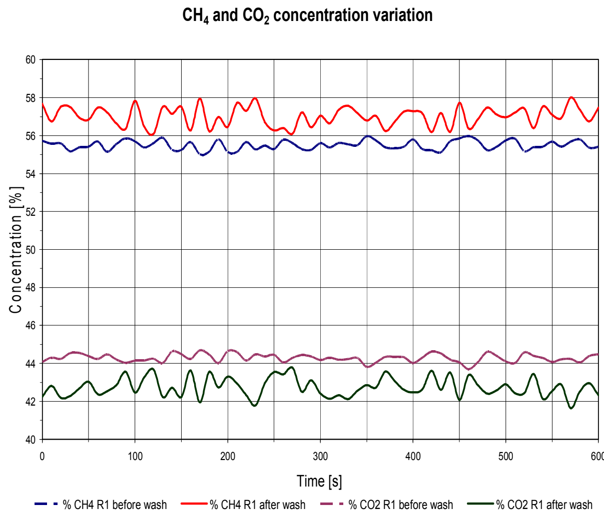

Fig. 26 - Methane and CO_2 concentrations for beech dust batch – reservoir no. 1 [16]

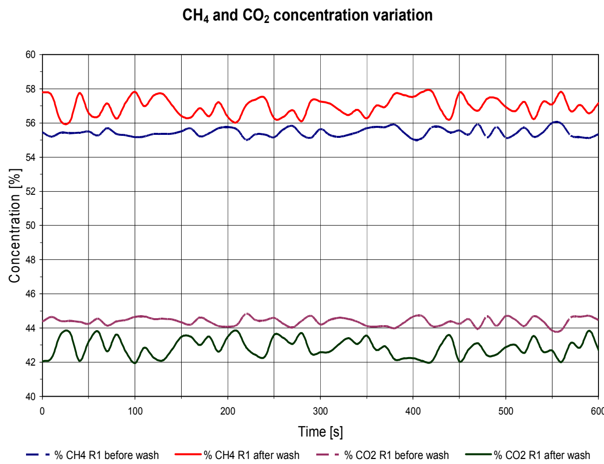

Fig. 27 - Methane and CO_2 concentrations for beech dust batch – reservoir no. 2 [16]

From the graphics it results that the methane concentration has approximately the same values for the reservoirs, with a maximum value of about 58 % by volume, while CO_2 concentration attempts as maximum values the range of 41 – 42 % by volume,.

Figures 27 and 28 present the methane and CO_2 concentrations for the linden dust batch.

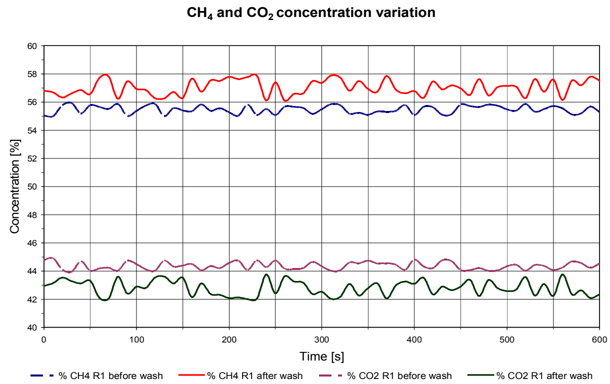

Fig. 28 - Methane and CO_2 concentrations for linden dust batch – reservoir no. 1 [16]

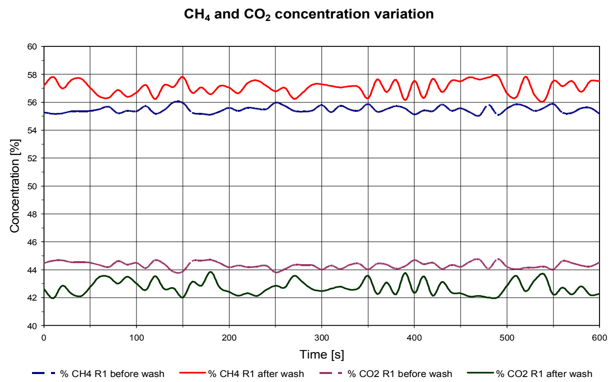

Fig. 29 - Methane and CO_2 concentrations for linden dust batch – reservoir no. 2 [16]

Through comparison with the values for the first batch, it can be observed that the CH_4 concentration is about the same for the maximum values, like the CO_2 concentration. The explanation resides in the fact that the material is woody and has a large percentage of ligno-cellulose, very difficult to decompose.

In Figures 29 and 30 the methane and CO_2 concentrations for the mix of maize and corn waste batch are presented.

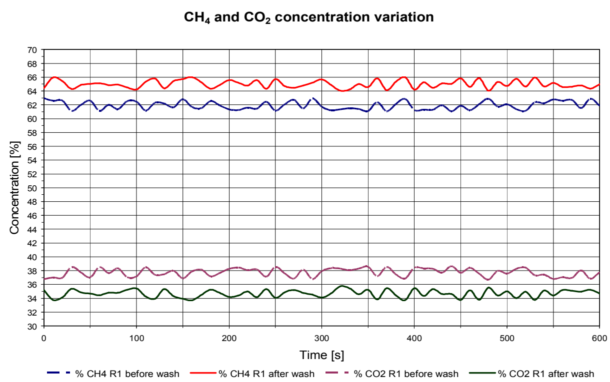

Fig. 30 - Methane and CO_2 concentrations for mix of maize and corn waste batch – reservoir no. 1 [16]

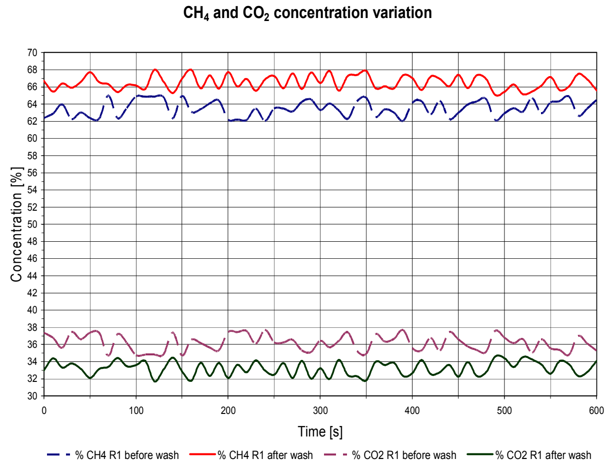

Fig. 31 - Methane and CO_2 concentrations for mix of maize and corn waste batch – reservoir no. 2 [16]

It results that the CH_4 concentration is with approximately 1 % larger for the second reservoir, this percentage influencing the CO_2 concentration.

Finally, Figures 31 and 32 bring the concentrations of methane and carbon dioxide in case of the corn waste batch.

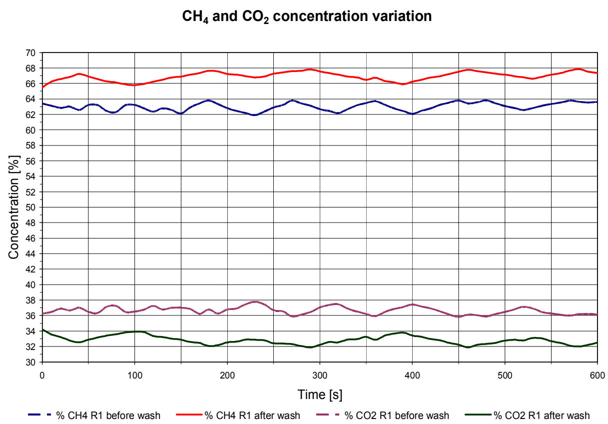

Fig. 32 - Methane and CO_2 concentrations for corn waste batch – reservoir no.1 [16]

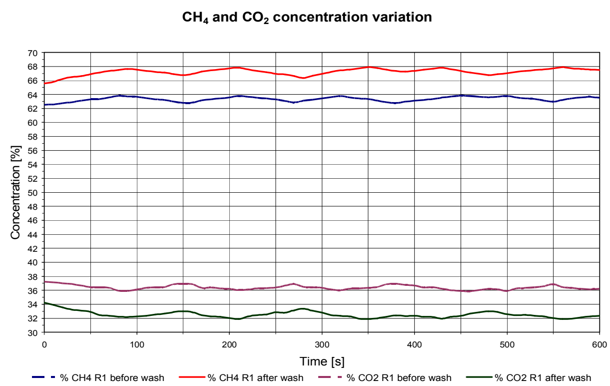

Fig. 33 - Methane and CO_2 concentrations for corn waste batch – reservoir no.2 [16]

By analyzing this batch one concludes that the maximum value interval achieved for methane is 67 – 68 % by volume, and also that this value influences the CO_2 concentration.

By comparison, it results that the last two batches (corn waste batch and mix of maize and corn waste batch) produced much more biogas than the first two, and this demonstrates the importance to find further solutions to solve the problem of the difficult degradation of the ligno – cellulose chains, or at least a complex technology to reuse the second generation waste, meaning the residues from the biogas production, in these particular cases. A possible solution recommended by the literature would be an acid hydrolysis, but through the process of neutralizing the acid, the result is often a salt, that decreases the speed of the formation of mathanogenic bacteria, and thus, the biogas production is reduced.

Because the heat value of the residual waste of the biogas process is relatively high, for a full recovery of the energy potential and a better balance, it is recommended to be co-incinerated with other fuels, so that the material is reused and residual quantity are minimized. One can also imagine steady alone facilities working independent only with biogas.

After the process of anaerobic fermentation, the residual material from each batch was analyzed from the point of view of the high and low calorific values, in order to establish further utilization, mainly if it can be used in other burning processes together with other fuels, for example in case of co-combustion. The obtained values are presented in Table 3, for each batch and each reservoir.

Table 3 – High and low calorific values for the used batches of material [16]

No.	Water ash free sample	High calorific value [kJ / kg]	Low calorific Value [kJ / kg]
1	Beech dust batch, reservoir no. 1	13195	11759
2	Beech dust batch, reservoir no. 2	12987	11463
3	Linden dust batch, reservoir no. 1	13254	11843
4	Linden dust batch, reservoir no. 2	13146	11721
5	Mix of corn and maize batch, reservoir no. 1	7356	6094
6	Mix of corn and maize batch, reservoir no. 2	7335	6044
7	Grains of corn batch, reservoir no. 1	4972	3673
8	Grains of corn batch, reservoir no. 2	4936	3645

The residual material with a high content of ligno-cellulose has a larger value for both the high and low calorific value, because of the fact that the cellulose chains are difficult to break, even with the help of an initial step, experimentally accomplished, consisting of an acid hydrolysis.

4 Conclusion

Biogas is a type of unconventional energy (RES) for the future; it is one way to transform a natural available waste resource into useful energy and thus might complete the present tendency of the growing impact upon global economy and peace of the reduced available amounts of fossil fuels, in the near future.

Biomass represents an inexhaustible energy resource that can be used partly or wholly for biogas production, both by anaerobic fermentation and other processes (aerobic fermentation, gasification), related technology for anaerobic fermentation process being used in the present.

Regionally and globally, stimulated investments are linked to the achievement of plants to produce biogas, a shift in which our country should join the current conditions.

The quality of the produced biogas is closely related to the type of waste biomass used, but by utilization of the byproducts (fertilizer or fuel) the economy of the process might turn into a favorable one.

From the graphics presented it results that the origin and quality of the input raw material used is very important, related with the type of biomass, the, the duration of the batch fermentation, and also the ration between solid matter and liquid volume.

The main parameters of influence for the process of anaerobic fermentation are the temperature regime, the pH of the suspension and the type of biomass and its chemical characteristics.

Special treatments such as CO_2 capture for the increasing of the heating value of the biogas, acid hydrolysis,

Biogas is a RES that should be added as application in different areas, especially for farmers and regional advantages. The benefits go not only to the environmental protection, but also they close the financial loop of the fuel costs that, in case of biogas is remaining in the local community, the same, that generates the input raw material for its production.

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