ANAEROBIC FERMENTATION IN EXPERIMENTAL APPLICATIONS AT SMALL SCALE

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REZUMAT: Lucrarea de faţă va sublinia câțiva parametrii specifici de proces (caracteristici generale, pH, temperatură) care implică influenţa procesului de fermentare anaerobă a două materiale biodegradabile diferite, grâu degradat şi coji de cartofi, în raport cu potențialul lor de a fi utilizate pentru obținerea de biogaz. Cele două materiale au fost studiate iar măsurătorile au fost efectuate în aceleași condiții, pentru același proces, pentru ambele loturi de material, la o scară mică în Laboratorul multifuncţional al Facultatii de Mecanica de la Universitatea "Politehnica" din Timişoara şi concluziile au fost luate în considerare.

Cuvinte cheie: reziduuri de biomasă, biogas, parametri de fermentare

ABSTRACT. The present paper will underline some of the specific process parameters (general characteristics, pH, temperature) involving the influence of anaerobe fermentation on two different biodegradable materials, degraded wheat and potato peelings relative to their potential in being used for obtaining biogas.The two varieties of materials were studied and measurements were conducted involving the same process conditions for both batches of material, on a small scale installation located in the Multifunctional Laboratory of the Mechanical Engineering Faculty from „Politehnica" University of Timişoara and conclusions were taken accordingly.

Key words: biomass residues, biogas, fermentation parameters

1. INTRODUCTION

Biomass is a renewable fuel that is discharged simultaneously by burning heat and delivers an amount of CO_2 equal to that consumed in its genesis. It is expected that biomass will play a major role in replacing fossil fuels contributing to a great extent at the use of renewable resources by the year 2010 [1].

Biogas is the combustible gas produced by the anaerobic digestion of organic material, e.g. animal manure, human excreta, kitchen remains, straws and leaves through the action of micro-organisms. Biogas is primarily composed of methane (CH_4) and carbon dioxide (CO_2), with smaller amounts of carbon monoxide (CO), hydrogen sulphide (H_2S), ammonia (NH_3), nitrogen (N_2) and oxygen (O_2) [2].

In 1776, for the first time, the Italian Physicist, Volta, demonstrated methane in the marsh gas, generated from organic matter in bottom sediments of ponds and streams. Under anaerobic conditions, the organic materials are converted through microbiological reactions into gases (fuel) and organic fertilizer (sludge). The mixture of gases is composed of 63 % by volume methane, 30 % by volume CO_2, 4 % by volume nitrogen and 1 % by volume hydrogen sulphide and traces of hydrogen, oxygen and carbon monoxide.

Anaerobic digestion is also a key technology for the treatment of large volumes of bio-waste generated in industrialized countries [3].

The growing interest in the gaseous bio fuel can be easily explained: it can be produced in a decentralised manner, it is highly efficient - yielding more than twice as much energy per hectare of energy crops than ethanol from similar crops - and it can be obtained in a straightforward way from a large variety of biomass resources (organic waste, manure, dedicated energy crops).

In Romania there are not in use today any biogas plants for vegetable waste (cellulose) in the absence of technology, not the raw material that is available in considerable quantities.

2. TECHNOLOGY

The research was made on a small scale installation designed and created for experimental studies related to the behavior of different types of biomass residues during the process of anaerobic fermentation.

In this paper there will be presented two types of materials, potato peelings and degraded wheat, with some determined chemical and physical properties and their behavior, during the influence of the main parameters of the process (temperature and pH) from the point of view of the degradation process. Images were carried out in order to visually determine the evolution of the degradation during time over a period of 40 days for each batch of material.

In Table 1 are presented the chemical characteristics of the four types of biomass residues.

In Figure 1 is presented the schematics for the small scale installation.

Table 1. *Chemical characteristic of the two types of biomass*

No	Sample	Water content [%]	Ash content [%]	Carbon content [%]	Nitrogen content [%]
1	Potato peelings	65,9	21,3	43,37	1,93
2	Degraded wheat	10,76	1,89	43,11	2,17

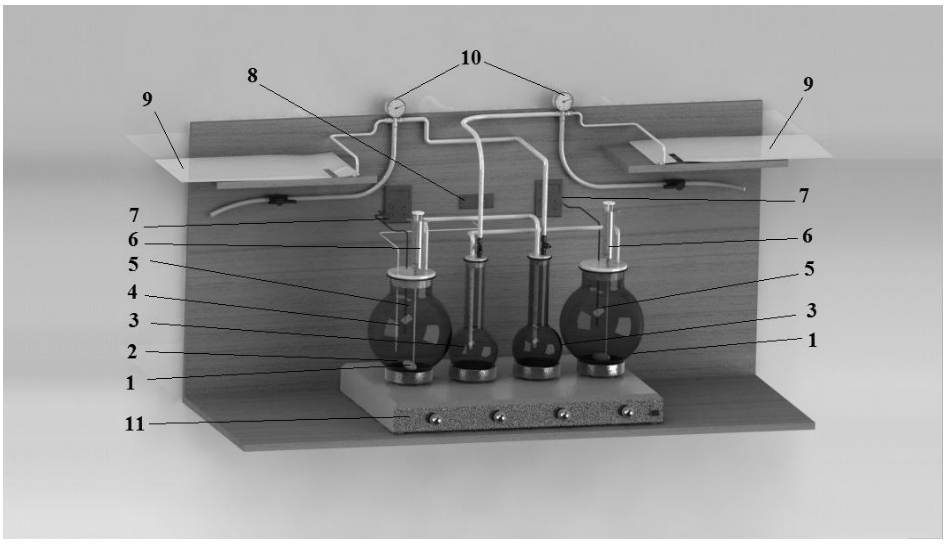

Fig. 1. *Schematics of the small scale installation*

1 – glass reactor with a total volume of 6 l; 2 – magnet place don the bottom of the 6l glass reactors for magnetic stirring; 3 – small glass reactor for biogas washing with water, with a total volume of 500 ml; 4 – thermocouple; 5 – pH sensors; 6 – system for pH correction and sample collecting; 7 – pH controllers; 8 – temperature controller; 9 – gas bags for biogas samples; 10 – pressure gauges; 11 – heating system.

In the next part, the process involved inside the installation is presented: inside the glass reactors (1) are inserted a semi-fluid suspension composed from fine-granulated biomass and water. Each glass reactor has on the bottom part a magnet (2) used for the magnetic stirring process in order to have a relatively homogenous material. From the glass reactors, the formed biogas will pass into the smaller glass reactors (3) half filled with water in order to “wash” the impurities of the biogas.

Each of the glass reactors (1) has inside a pH sensor (5) which is controlled with pH controllers (7), and also a thermocouple (4) controlled with the help of a temperature controller (8) in order to assure the necessary temperature for the process. The installation is equipped with special gas bags (9) in order to take samples if necessary and pressure control with the help of pressure gauges (10) in case of overpressure.

The temperature regime is assured with the help of the heating device (11) which allows 2 batches to be analyzed separately. The installation was built in order to support two batches of material under the same temperature conditions in order to better observe and make comparisons over the general particularities of each used material.

3. RESULTS AND DISCUSSION

In figures 2 and 3 are presented the temperature and pH variation for the two batches

From figure 2 it can be observed that the imposed temperature regime is between 34 – 35 °C, this parameter being controlled in order to assure the same conditions for both batches

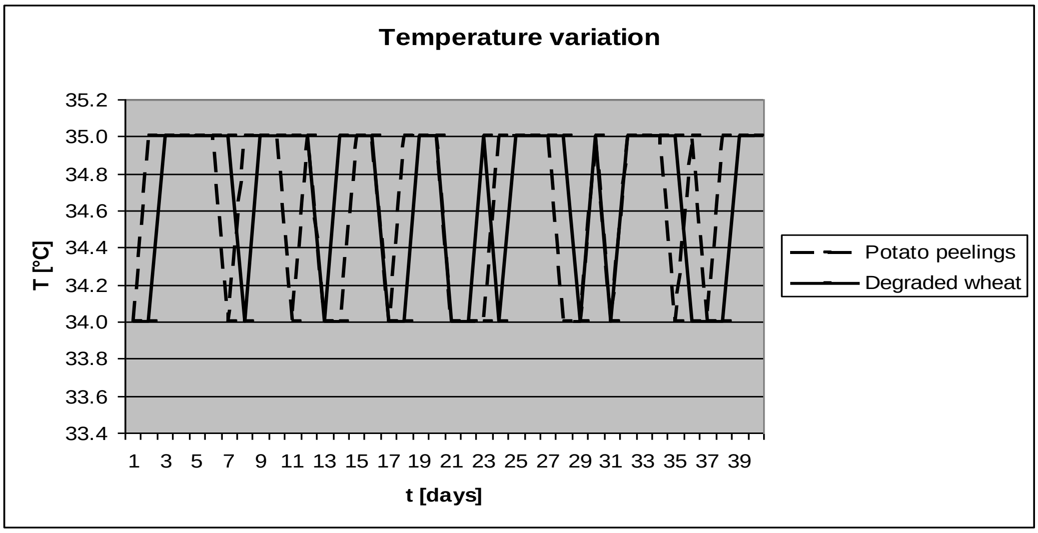

Fig. 2 – *Temperature variation*

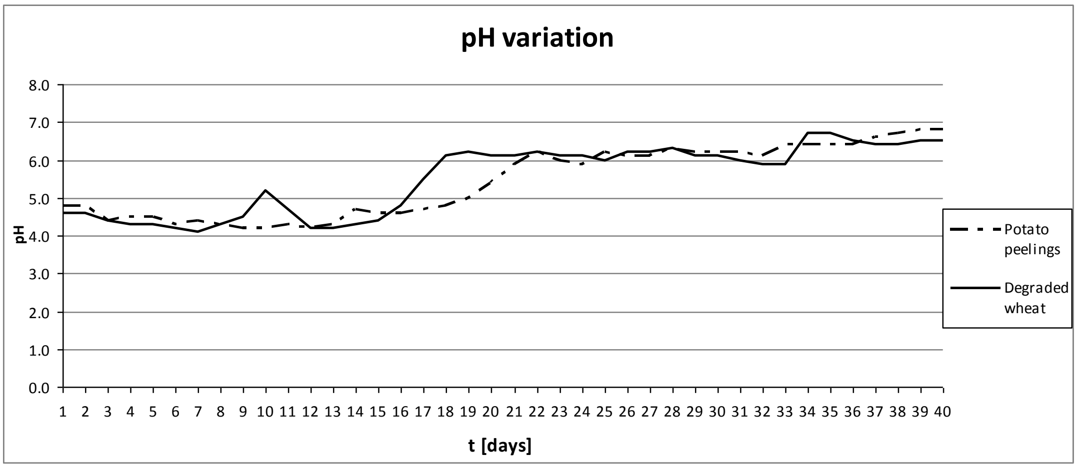

Fig. 3 – *pH variation*

Figure 3 underlines the pH variation for the batches indicating that the degraded wheat material has a fluctuating variation in time, due to pH corrections imposed by the low pH in the first period of time, with values corresponding to an optimum pH after 30 days of process.

The potato peelings batch has a rather linear ascending evolution in time, relative to the first batch with values inside the domain between 6 and 7 after approximately 20 days of process.

For an accurate description of pH variation with temperature and time it was proposed a polynomial equation of second degree expressed by equation 1 [4, 5].

$$y = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + a_3 \cdot x_1 \cdot x_2 + a_4 \cdot x_1^2 + a_5 \cdot x_2^2 \quad (1)$$

where: a_i – equation coefficients; y – pH; x_1 – temperature [ºC] ; x_2 – time, [days].

The coefficients values in the case of second degree polynomial regression are corresponding to the minimum of the function:

$$S = \sum_{j=1}^{m} (\hat{y}_j - (a_0 + a_1 \cdot x_{1j} + a_2 \cdot x_{2j} + a_3 \cdot x_{1j}^2 + a_4 \cdot x_{1j} \cdot x_{2j} + a_5 \cdot x_{2j}^2))^2$$

Through annulment of the partial derivates of S function in connection with a_i coefficients, a linear equations system is obtained. The coefficient matrix of the system A and the free coefficients vector, B are:

$$A = \begin{bmatrix}
\sum_{j=1}^{m} 1 & \sum_{j=1}^{m} x_{1j} & \sum_{j=1}^{m} x_{2j} & \sum_{j=1}^{m} x_{1j}^2 & \sum_{j=1}^{m} x_{1j} \cdot x_{2j} & \sum_{j=1}^{m} x_{2j}^2 \\
\sum_{j=1}^{m} x_{1j} & \sum_{j=1}^{m} x_{1j}^2 & \sum_{j=1}^{m} x_{1j} \cdot x_{2j} & \sum_{j=1}^{m} x_{1j}^3 & \sum_{j=1}^{m} x_{1j}^2 \cdot x_{2j} & \sum_{j=1}^{m} x_{1j} \cdot x_{2j}^2 \\
\sum_{j=1}^{m} x_{2j} & \sum_{j=1}^{m} x_{1j} \cdot x_{2j} & \sum_{j=1}^{m} x_{2j}^2 & \sum_{j=1}^{m} x_{1j}^2 \cdot x_{2j} & \sum_{j=1}^{m} x_{1j} \cdot x_{2j}^2 & \sum_{j=1}^{m} x_{2j}^3 \\
\sum_{j=1}^{m} x_{1j}^2 & \sum_{j=1}^{m} x_{1j}^3 & \sum_{j=1}^{m} x_{1j}^2 \cdot x_{2j} & \sum_{j=1}^{m} x_{1j}^4 & \sum_{j=1}^{m} x_{1j}^3 \cdot x_{2j} & \sum_{j=1}^{m} x_{1j}^2 \cdot x_{2j}^2 \\
\sum_{j=1}^{m} x_{1j} \cdot x_{2j} & \sum_{j=1}^{m} x_{1j}^2 \cdot x_{2j} & \sum_{j=1}^{m} x_{1j} \cdot x_{2j}^2 & \sum_{j=1}^{m} x_{1j}^3 \cdot x_{2j} & \sum_{j=1}^{m} x_{1j}^2 \cdot x_{2j}^2 & \sum_{j=1}^{m} x_{1j} \cdot x_{2j}^3 \\
\sum_{j=1}^{m} x_{2j}^2 & \sum_{j=1}^{m} x_{1j} \cdot x_{2j}^2 & \sum_{j=1}^{m} x_{2j}^3 & \sum_{j=1}^{m} x_{1j}^2 \cdot x_{2j}^2 & \sum_{j=1}^{m} x_{1j} \cdot x_{2j}^3 & \sum_{j=1}^{m} x_{2j}^4
\end{bmatrix}$$

$$B = \begin{bmatrix} \sum_{j=1}^{m} \hat{y}_j \\ \sum_{j=1}^{m} x_{1j} \cdot \hat{y}_j \\ \sum_{j=1}^{m} x_{2j} \cdot \hat{y}_j \\ \sum_{j=1}^{m} x_{1j}^2 \cdot \hat{y}_j \\ \sum_{j=1}^{m} x_{1j} \cdot x_{2j} \cdot \hat{y}_j \\ \sum_{j=1}^{m} x_{2j}^2 \cdot \hat{y}_j \end{bmatrix}$$

Using MATLAB software the equation system was solved and there were analyzed the experimental data.

The obtained data together with the generated surfaces from the statistical mathematical models are presented in figures 4 and 5.

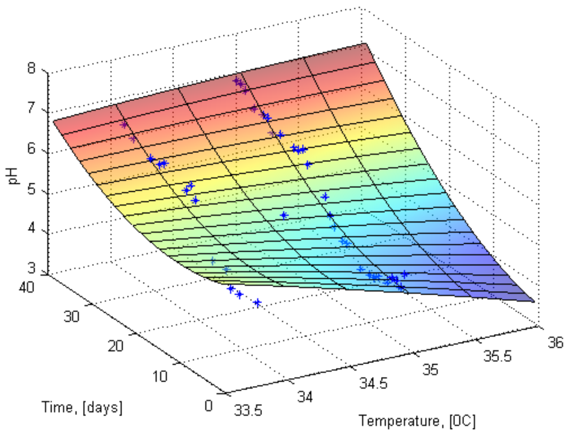

Fig. 4. pH *evolution in connection with temperature T and time t for a batch containing potato peelings*

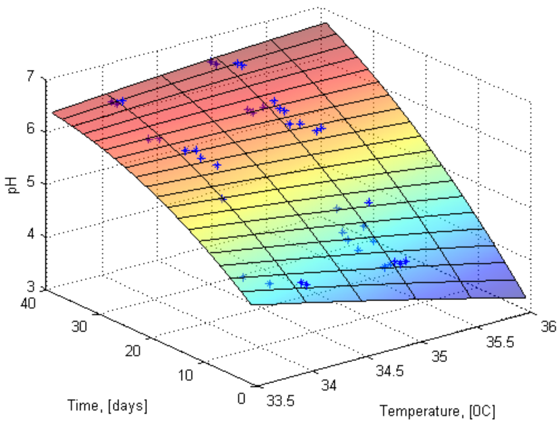

Fig. 5 - *pH evolution in connection with temperature T and time t for a batch containing degraded wheat*

From the graphics it can be observed that the pH variation has an evolution form acid to neutral or basic levels in time. This process can be explained by the characteristic pH values connected with the phases from which the material starts to degrade (acid phase) until the
biogas production where the degradation process is much more intense and the pH tends for a neutral value.

The equation for the obtained mathematical statistical models after the linear multiple regressions are presented in Table 2. They are valid on the studied field of values

Table 2. *Equations of the obtained statistical models*

Batch	Equation
Potato peelings	$y = 1.1359 \cdot x_1 - 0.8826 \cdot x_2 + 0.0251 \cdot x_1 \cdot x_2 - 0.0289 \cdot x_1^2 + 0.0019 \cdot x_2^2$
Degraded wheat	$y = 0.7417 \cdot x_1 - 0.4688 \cdot x_2 + 0.0166 \cdot x_1 \cdot x_2 - 0.0182 \cdot x_1^2 - 9.0675e{-}004 \cdot x_2^2$

Where : x_1 – temperature
x_2 - time

After the computation of the model coefficients it is necessary to make a comparison between model predictions and experimental data. For adequacy indicators there were used the dispersion and R correlation coefficient (Table 3)

- dispersion : $$\sigma^2 = \frac{\sum_{i=1}^{n} (y_{i\,exp} - y_{icalc})^2}{n-1} \quad (4)$$

- R correlation coefficient:

$$R = \sqrt{1 - \frac{\sum_{i=1}^{n} (\hat{y}_i - y_{icalc})^2}{\sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2}} \quad (5)$$

Table 3. *Adequacy indicators for determined statistical model*

Batch	Dispersion, σ^2	Correlation coefficient, R
Potato peelings	0.1611	0.8981
Degraded wheat	0.2442	0.8560

The values for the presented adequacy coefficients in Table 3 are indicating a satisfactory correlation between the determined statistical model and experimental data. This confirms the fact that obtained mathematical equations describe with sufficient accuracy the pH evolution in time as a function of temperature.

4. CONCLUSIONS

The presented paper underlined some of the general characteristics for different substrates belonging to cereal and food area of interest, both being unusable in other applications, as an example of the potential of the different sources of clean energy that can be capitalized through different relatively simple technologies.

During the experiments it was determined that both pH and temperature are important factors during the anaerobe fermentation, both in terms of influencing the internal suspension of material and with application to larger levels for determining the potential quality and quantities for the produced biogas.

Using this kind of technology with application of all kinds of vegetable residues, it can improve the recovery of energy potential for materials that usually are not used for any kind of activities, while obtaining a clean fuel with no dangerous impact over the environment.

Unlike fossil fuel combustion, biogas production from biomass is considered CO_2 neutral and therefore does not emit additional Greenhouse Gases (GHG) into the atmosphere.

Finally, as a general conclusion related to the presented topic, biogas production from anaerobic digester presents the additional advantage of treating organic waste and reducing the environmental impact of these wastes. It contributes to a better image of the farming community while reducing odour, pathogens and weeds from the manure and producing an enhance fertilizer easily assimilated by plants.

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