Experimental approach for biogas production from biowaste

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Abstract— Biomass represents one of the most important sources of clean energy which can be used in order to obtain, using different technologies, unconventional fuels which can replace, partially or totally, the existing fossil fuels that are used today. Connected with the existing status and importance for biomass, in the paper are underlined aspects regarding the usage of different types of material (degraded cereals, peelings, etc.) for obtaining biogas using the anaerobic fermentation process. The paper highlights also the general presentation for a pilot installation and a small-scale installation, both intended to be used for the further analysis of the characteristics for the presented materials.

Keywords— Biomass, biogas, anaerobic fermentation, small - scale installation, pilot installation.

I. INTRODUCTION

The energy need of world rapidly grows by consuming all the stock of energy resources in nature. When the effects of the petroleum crises in 1970's and the gulf war in 1991on petroleum reserves are considered, it is clear that there is not any other option for all the world to use the reserves in hand in the best way and direct towards to new energy resources [1].

Scenarios have shown that the energy demand will increase during this century by a factor of two or three as result of the population growth and energy consumption per capita. At the same time, concentrations of greenhouse gases (GHGs) in the atmosphere are raising rapidly, the fossil fuel derived CO_2 emissions being the most important contributor [2].

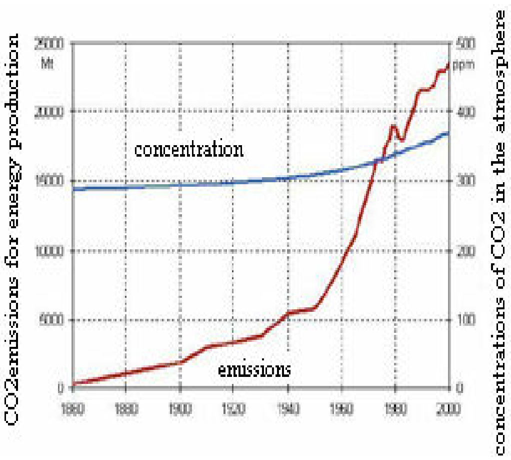

Fig. 1. The level of CO_2 emissions in the atmosphere [3]

Currently, approx. 85...90% of annual energy consumed on Earth, is produced by burning fossil fuels. In 2030, it is estimated that in terms of used source, the structure of energy production will be: 75…85% of conventional fuel combustion, 10…20% of nuclear fission, 3…5% of waterpower, approx. 3% of solar and wind energy [4].

Thus, the fundamental concern is the availability of resources, the findings being at times optimistic, pointing out that science, technology and the fact that man would be able to reach outer space will solve the problem, and at times detained, being said that it would not be appropriate to rely on the continuous upgrading of technologies able to provide cheap energy, and at times even pessimistic (such as the findings in the Report to the "Club of Rome" entitled "Limits to Growth", a study published by D.H. Meadows, and others, in 1972), foreseeing the depletion of resources in less than a century and the collapse of humanity [5].

Connected with the elements stated above, renewable energy technologies do not simply produce energy, heat and transport fuel, but also offer the opportunity to live in the footsteps of a reasonable future development. In Europe and other industrialized regions the main reason for the development of renewable energy is the environment, in particular concern in relation to global climate change and the need to improve security and diversity of energy supply. In the developing countries, it promises a new hope for renewable primary energy supply in regions without conventional energy and provides an opportunity for sustainable development [6].
Consequently the development and research is focused on increasing the efficiency of energy systems and on integration of renewable power sources into the energy production. Europe shows great interest in alternative power sources such as solar energy, heat pumps, wind energy etc [7].

As fossil fuels are not only limited, but also contribute to global warming, a transition towards a sustainable energy supply is urgently needed. One important element of this transition is the increased use of biomass to generate renewable energy [8].

In the last years the biomass has attracted considerable attention as a renewable energy source because it is the only renewable source of fixed carbon. Biomass has been recognized as a major world renewable energy source to supplement declining fossil fuel resources. Biomass appears to be an attractive feedstock for three main reasons. First, it is a renewable resource that could be sustainable developed in the future. Second, it appears to have formidably positive environmental properties resulting in no net releases of carbon dioxide and very low sulphur content [9].

Currently, biomass covers more than 10% of the world's primary energy demand (about 50 EJ/year) and biomass resources are by far not fully used [8].

About 25% of the usage is in industrialized countries, where a significant level of investment in environmental protection has been made to meet emissions standards, especially air emissions. The other 75% of primary energy use of biomass is in heat production for developing country household energy needs and in process heat production for biomass-based industries through the use of their generated residues [10].

During the recent time period biomass 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 on planning and storing the available energy resource [11].

For the near future, increasing biomass use is considered to be essential in meeting the targets set out by the EU. Biomass sources are wastes, energy crops, agricultural residues or residues from forests. The utilization of energy crops in the near future is uncertain, but in the longer term potentially the largest contributor to bio-energy production. As the potential from residues and wastes is already utilized to a high degree in the EU, a further growth in biomass production should come from energy crops [12]. As considered, bioenergy from renewable resources is already today a viable alternative to fossil fuels; however, to meet the increasing need for bioenergy several raw materials have to be considered. Lignocellulose is the most abundant organic material on earth and is therefore a promising raw material for bioenergy production. Lignocelluloses materials contain cellulose and hemicellulose that are bound together by lignin [13]. Considering the possibilities involved by using different types of materials in order to capitalize their energetic potential, there are different technologies used today and available both for small and large scale. Production of "green energy" from biogas, which is among the renewable energy sources, promises an environmentally less damaging way of obtaining energy by reducing CO_2 emissions into the environment and reduces energy dependence on imported energy sources.

Since it is carried out by a consortium of microorganisms and depends on various factors like pH, temperature, C/N ratio, etc., it is a relatively slow process.

Also lack of process stability, low loading rates, slow recovery after failure and specific requirements for waste composition are some of the other limitations associated with it [14].

Even if connected with those setbacks, biogas production is considered to be of great importance for the sustainable use of agrarian biomass as renewable energy source.

Biogas technology offers a very attractive route to utilize certain categories of biomass for meeting partial energy needs. In fact proper functioning of a biogas system can provide multiple benefits to the users and the community resulting in resource conservation and environmental protection [14].

The existing composition in biogas is mainly methane and CO_2, but it also contains hydrogen sulphide and other sulphur compounds, compounds such as siloxanes and aromatic and halogenated compounds. Although the amounts of trace compounds are low compared to methane, they can have environmental impacts such as stratospheric ozone depletion, the greenhouse effect and/or reduce the quality of local air [6].

The biogas production process is complex and sensitive since several groups of microorganisms are involved. The important processes in anaerobic digestion are hydrolysis, fermentation, acetogenesis, and methanogenesis, where hydrolysis is subject to the fermentation process, while acetogenesis and methanogenesis are linked. The hydrolysis step is an extra-cellular process where the hydrolytic and fermentative bacteria excrete enzymes to catalyze hydrolysis of complex organic materials into smaller units. The hydrolyzed substrates are then utilized by fermentative bacteria. Fermentation products such as acetate, hydrogen and carbon dioxide can directly be used by methanogenic microorganisms producing methane and carbon dioxide, while other more reduced products such as alcohols and higher volatile fatty acids are further oxidized by acetogenic bacteria in syntrophic with the methanogens [15] [18].

Biogas is the renewal energy that is used to replace firewood, charcoal, oil, liquid petroleum gas, etc. It is also able to apply to cooking gas directly as same as liquid petroleum gas. This is more convenience for usability than using firewood or charcoal without smoke and ash. The biogas can be applied to use in lamps or electric generators for light generation. It is also used to generate heat and applied to use with all kind of engine instead of oil. The biogas that is used for fuel energy must contain more than 50% of methane [16].

Related with the aspects presented above, the next section of the paper will present in short the pilot installation and the small scale installation built at the Unconventional Energies Laboratory of the Mechanical Engineering Faculty in order to study the particularities of the anaerobic fermentation process and for the process of degradation on different types of biomass material.

II. PILOT AND SMALL - SCALE INSTALLATION DESCRIPTION AND OPERATION

In Figure 2 and 3 is presented the pilot installation built at the Unconventional Energies Laboratory within the Mechanical Engineering Faculty for the experimental study of the anaerobic fermentation process.

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 with the help of the pump (2) and introduced into the fermentation reactors (3). The correction agent tank for the pH 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) and after that, through a system used for retaining CO_2 (6), after which takes place the CO_2 desorption and the compression of the CO_2 in the adjacent system (7) and the purified biogas is sent for being used (8). The used material is discharged through the means of a gravimetric system (9), and the solid material is retained for being dried using the natural drying, and after that is sent to a compost deposit for being used as a soil fertilizer. A part of the resulting liquid is neutralized when the case, in the system

(10) and sent to the sewerage network, or is transported by the recirculation pump (2) from the suspension preparation tank (1). The fermentation reactors are thermostat heated with the system (11). For the homogenization of the suspension is used a bubbling system (12) made by polypropylene pipes 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.

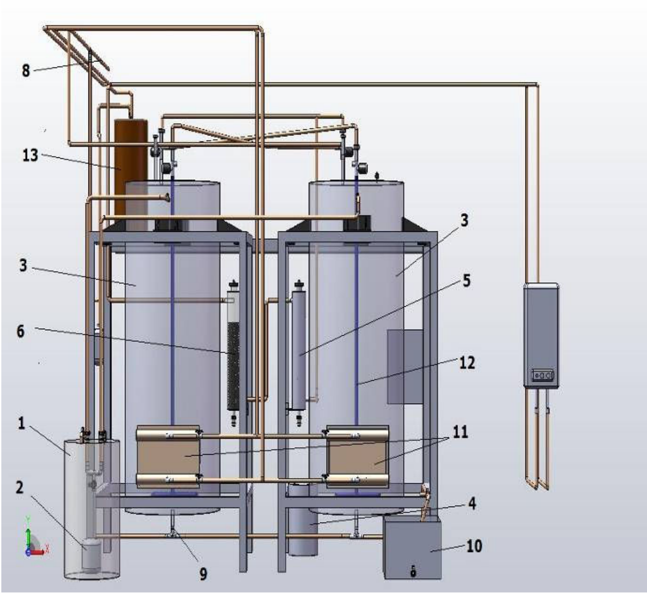

Fig. 2. Pilot installation schematics [17]

Fig. 3. Front view of the pilot installation [17]

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 desorption and compression, 8 – consumer , 9 – gravimetric system, 10 – system for neutralizing the resulting liquid, 11 – heating system, 12 – bubbling system, 13 – small tank for biogas samples.

With the help of this installation there can be made experimental analysis related to biogas quality and quantity using different sorts of wood and agricultural biomass residues.

Also the installation contains a separate system for CO_2 retention from the produced biogas.

In Figure 4 is presented the schematic presentation of the system.

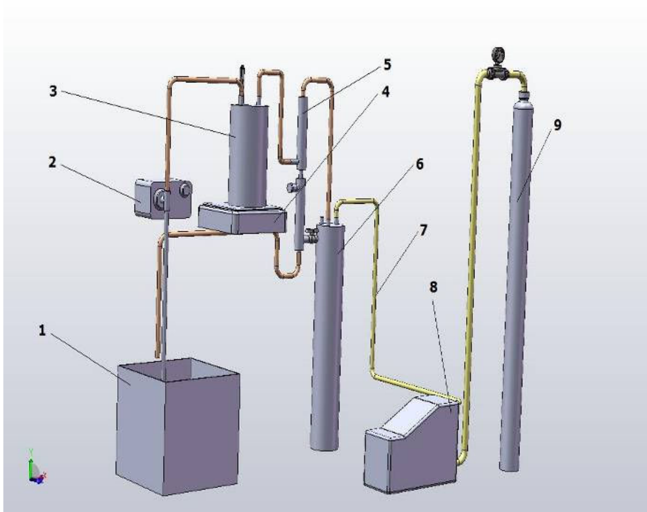

Fig. 4. Schematic presentation of the CO_2 retention system [17]

The system is composed from a tank (1) from which the water is passed by the means of a dosing pump (2) similar with the dosing pumps used for the pH correction, a stainless steel tank (3) positioned on an heating device (4), a liquid separator (5), a buffer tank (6), from which the gas is aspirated with the help of a Haug compressor and inserted in a cylinder at a pressure of about 10 – 26 bar. The temperature inside the stainless steel tank can reach values of 50 – 60 °C.

In Figure 5 is presented the small - scale installation schematics.

Fig. 5. Small - scale installation image [17]

As can be seen in Figure 4 presented above, the anaerobic fermentation reactors are bubble glass resistant to variations of temperature, resistant to pressures of 0.5 – 0.6 bar, having a useful volume of about 2 liters. To ensure that gas washing is formed within them, they are connected through flexible tubes of two heat-resistant glass containers (the two vessels from the middle), with a useful volume of 0.5 liter containing approximately 200 ml of water. The gas formed in anaerobic fermentation reactors will thus pass through the flexible tubs to the bottom of small vessels to wash impurities.

To avoid inhibition of anaerobic fermentation process, the reactors with capacity of 2 liters will be covered with foil opaque material.

Given that lack of homogenization by mixing can lead to inhibition of the process by developing a film on the surface of the suspension, each of the two reactors are built-in bottom and agitation is a magnet with a magnetic stirrer with adjustable speed.

To avoid the mal function of anaerobic fermentation process, the reactors will be covered with opaque material. Given the fact that lack of homogenization by mixing the suspension can lead to inhibition of the process by developing a film on the surface of the upper part of suspension, each of the two reactors contains a magnet and the agitation occurs through a magnetic stirrer, with adjustable speed (Figures 6 and 7).

Fig. 6. Magnet located at the bottom of the glass vessel [17]

Fig. 7. Magnetic stirrer [17]

In Figure 8 is presented a general view of the reservoirs with the material inside them, during the anaerobic fermentation process.

Fig. 8. Front view of the glass reservoirs filled with material suspension

The stirring process is developed on a daily basis, to ensure proper mixing of material inside glass vessels. Also the small scale installation is equipped with two pH sensors and two pH controllers in order to obtain information regarding the pH of the analyzed materials in real time. In this manner is possible to determine the pH value characteristic for each type of material before and after corrections, in order to maintain its value on a relative neutral level.

In Figure 9 are presented the pH controllers.

Fig. 9. pH controllers for the small scale installation

The obtained biogas is deposited inside two special gas bags for further analysis (Figure 12).

In Figures 10 and 11 are presented the system composed of the temperature controller and the thermocouple (type J).

Fig. 10. Temperature controller [17]

Fig. 11. Type J Thermocouple [17]

Fig. 12. Biogas storing special bag [17]

The stirring process is made on a daily basis to ensure proper mixing of material inside glass vessels. The obtained biogas is deposited inside two special gas bags for further analysis.

The temperature of the process is controlled with system made from a controller and a temperature sensor.

III. GENERAL PRESENTATION FOR DIFFERENT TYPES OF BIOMASS

Having in mind that in literature are studied different types of material used for obtaining biogas using the anaerobic fermentation process, this part will be a short presentation of different sorts of biomass intended to be analyzed by the authors from the point of view of their behavior during the degradation process and the anaerobic fermentation process.

In Table I are presented some of the general characteristics for different types of degraded biomass of vegetal composition.

Table I. General characteristics for the samples

No	Name	Water content [%]	Ash content (dry base) [%]	Net calorific value (dry base) [MJ/kg]
1	Barley	12.4	3.2	16.9
2	Two-row barley	13.0	3.7	16.6
3	Oatmeal	11.2	5.2	18.0
4	Rye	12.9	2.9	16.8
5	Rice	17.2	0.2	14.7
6	Clover	32.7	10.5	18.0
7	Potato peelings	65.9	21.3	16.4
8	Banana peelings	33.6	18.6	16.2
9	Corn cobs	19.7	3.6	17.2
10	Corn stables	53.8	8.4	16.6

In Table II are presented the Carbon and Nitrogen content for the same materials.

Table II. Carbon and Nitrogen content for the samples

No.	Name	Carbon content (dry base) [%]	Nitrogen content (dry base) [%]
1	Barley	45.05	2.25
2	Two-row barley	45.19	2.18
3	Oatmeal	46.53	2.32
4	Rye	45.74	1.82
5	Rice	44.56	1.27
6	Clover	45.21	4.76
7	Potato peelings	43.37	1.93
8	Banana peelings	42.29	1.32
9	Corn cobs	45.74	0.66
10	Corn stables	45.15	0.85

In Figures 13 to 22 there are presented images for degraded barley, degraded two row barley, degraded oatmeal, degraded rye, potato peelings, banana peelings, corn cobs and corn stalks.

Fig. 13. Degraded barley

Fig. 14. Degraded two row barley

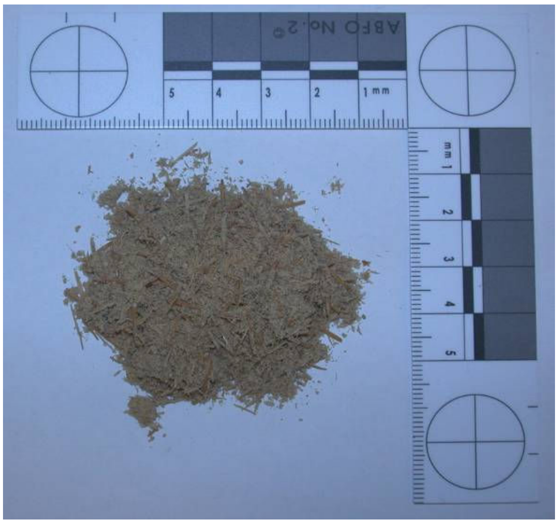

Fig. 15. Degraded oatmeal

Fig. 16. Degraded rye

Fig. 17. Potato peelings

Fig. 18. Banana peelings

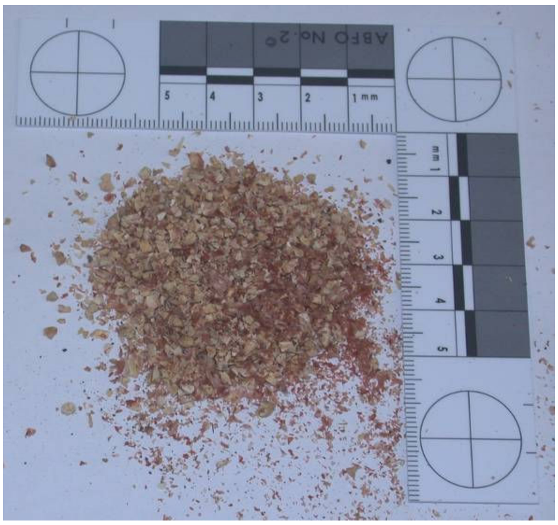

Fig. 19. Corn cobs

Fig. 20. Corn stalks

Fig. 21. Degraded rice

Fig. 22. Clover

From all the figures it can be observed that the covered types of material is the cereal part, the lignocellulose part and also some of the vegetables that contain large quantities of starch, which is very appropriate in regards of obtaining large quantities of biogas with good properties in regards of methane content.

The temperature regime that is to be used will be the mesophilic one, with values of temperature inside the range of 30 – 38°C.

It is also very important to determine the Carbon and Nitrogen content inside the studies materials because the ratio C/N is crucially important in connection with the anaerobic fermentation process. The duration of the batches is also important for the quality and quantity of the obtained biogas and the degradation process for each material will be a very important factor in determining the capitalization potential both in obtaining biogas and fertilizer agent, as a secondary product after the anaerobic fermentation process.

IV. CONCLUSIONS

Biomass is considered to be one of the most important sources of energy that can be used in order to recover, through the means of clean technologies, the energetic potential of different types of materials.

As observed, it is important to determine exactly the type of material used in order to obtain good quality biogas and in large quantities.

The most important parameters which are to be considered during the anaerobic fermentation process are temperature and pH, each with relevant impact over the good development of the process.

Another factor which has to be remembered is the residence time of the material inside the reactor, which depends both on its determined characteristics (C / N ratio) and the temperature regime which is set by the user.

Also, the initial characteristics of the used material are to be acknowledged in order to have a general view over the potential related with the degradation process in which the material can be transformed partially or almost entirely in another form of energy – biogas.

The samples presented in this study belong to the vegetal domain and have different elementary compositions, related with the starch or ligno - cellulose content, their composition being of great importance in concordance with the degradation potential (the cellulose in much harder to be degraded than starch), thus the relevance for using them for different experimental studies.

The mesophilic regime for temperature (30 – 38 ºC) was set for its advantages related to obtaining good quality biogas in large quantities, over a reasonable period of time (30 – 60 days), thus being simulated the conditions for obtaining biogas, which will be then applied on a larger scale, using the pilot installation, on the best sorts of biomass which are to be determined after implementing the degradation process to all the used types of material.

As a general conclusion, the relevance of determining the general characteristics for different types of material (water content, net calorific value, ash content, Carbon content, Nitrogen content, Carbon / Nitrogen ratio), the temperature regime (cryophilic, mesophilic, thermophilic), and the control of the pH values in the biogas production context is of great importance because of the possibilities involved by the potential use of different types of degraded materials from different fields of interest, both in research or industrial domains.

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