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Anaerobic Digestion Performances of Agricultural Biomasses Mixed with Different Kinds of Wastewaters

A.E. Cioabla[*] and G.A. Dumitrel[**]

[*] POLITEHNICA University Timisoara, Faculty of Mechanical Engineering, Bv. M. Viteazu, nr. 1, 300222, Timisoara, Romania, adrian.cioabla@upt.ro

[**] POLITEHNICA University Timisoara, Faculty of Industrial Chemistry and Environmental Engineering, Bv. Vasile Parvan, nr. 6, 300223, Timisoara, Romania

Abstract: Nowadays, the need for renewable sources of energy becomes more and more important, meaning that the necessity for research and viable solutions in this open field is of vital importance. Romania, as a UE member, must embrace the current policies relative to finding different solutions tailored to its potential and needs in order to obtain at least a certain degree of energetic independence from a renewable energy point of view. In this context, biogas, as a renewable energy carrier, can be one of the many possible solutions that have to be taken into account when it comes to finding a way to capitalize degradable materials which do not have many other applications. The present paper provides information on the performances of anaerobic digestion of different substrates obtained by mixing cereal degraded materials with different types of wastewater.

Keywords: agricultural biomass, wastewater, biogas, anaerobic digestion.

1. Introduction

Due to the continuous development of human society, conventional energy sources have begun to diminish more and more, approaching exhaustion. In addition, the use of fossil fuels has undesirably affected the quality of the environment and, implicitly, human health [1-3]. It was the moment when mankind began to search for alternative energy sources that would satisfy the following criteria:

- be cheap;
- be inexhaustible;
- do not have a negative impact on the environment [4].

Biomass is the first form of energy used by humans, representing the most abundant renewable resource on the planet.

According to legislation, biomass is the biodegradable fraction of products, wastes and residues from agricultural, and the biodegradable fraction of industrial and urban wastes [5]. In this category we include: agricultural residues and by-products, energy crops, animal wastes, organic wastes from industry, organic fraction of urban solid wastes and sewage sludge from water treatment plants [6, 7].

Anaerobic digestion is the complex biological process by which, in the absence of oxygen the organic substance is transformed into biogas [9, 10]. The stages of the anaerobic digestion process are: hydrolysis, acidogenesis, acetogenesis, metanogenesis.

At the end of the anaerobic digestion process, biogas and the residue, called digestate, are produced.

Biogas can be used for the production of heat, in cogeneration plants for the production of electric and thermal energy or, it can be treated for further use in fuel cells to generate biofuels or for gas supply.

Digestate can be subjected to composting or can be used as a fertilizer in agriculture [11].

Based on previous studies, the purpose of the present work was to compare the digestion performance of different mixtures having in the composition a cereal biomass and wastewater.

2. Experimental

2.1. Substrates

The substrates investigated were:

- degraded barley mixed with wastewater from treatment plant;
- degraded rye mixed with wastewater from treatment plant;
- degraded barley mixed with wastewater from beer factory;
- degraded rye mixed with wastewater from beer factory.

During the tests there were not used any inoculums, catalysts or other enzymes.

2. Analysis methods

The following characteristics of each substrate were measured: the hygroscopic moisture content, the ash content, the mean calorific value, the carbon, nitrogen and volatile content. The determinations were made according to the following standard methods:

- EN 14774 – Solid biofuels – Determination of moisture content – Oven dry method (parts 2 and 3) [12];

- EN 14775 – Solid biofuels –Determination of ash content [13];
- EN 14918 - Solid biofuels – Determination of calorific value [14];
- EN 15104 – Solid biofuels – Determination of total content of carbon, hydrogen and nitrogen – Instrumental methods [15];
- EN 15148 – Solid biofuels – Determination of the content of volatile matter [16].

All analyses were performed in duplicate.

2. Experimental set-up

The small scale installation used for anaerobic digestion testing is located at the Mechanical Engineering Faculty, Politehnica University Timisoara.

The fermentation process was held for 35 days, at a constant temperature (between 35 and 37 °C), in order to observe the pH evolution, the quantity of biogas produced and its composition in terms of CH_4 and CO_2 percentages.

During the process a solution of 20% NH_3 was used in order to correct the pH values.

The test rig used for producing biogas from biomass through anaerobic digestion is presented in figure 1.

The components of the small-scale installation are: 1 – thermal glass reactors with a total volume of 6 L used for dark fermentation; 2 – magnets positioned at the bottom of the glass vessels used for magnetic stirring of the used material suspensions; this system allows also the manual stirring / agitation; 3 – device used for heating the suspension inside the reactors; 4 – thermocouple used for temperature control; 5 – system for sampling and pH correction of the suspensions; 6 – syringe used for sampling and pH correction system; 7 - pH controllers connected to pH sensors placed inside the reactors in order to determine in real time the pH value of the suspension; 8 – temperature controller connected with the thermocouples; 9 – gas bags with a total volume of 2 L dedicated for sampling the obtained biogas from the fermentation process.

The gas analyzer used to analyze the biogas was a DELTA 1600 S IV type, which allows the determination of methane and carbon dioxide composition up to 100% by volume.

3. Results and Discussion

In the beginning of the experiments the raw materials were characterized. The corresponding values are presented in table 1.

From table 1, we can notice that the properties of barley and rye are closer one to each other. As concern the two wastewaters used inside the experiments it can be observed that the ash content is very high making them unsuitable for firing processes as base materials. The calorific value is relatively high by comparison with the cereal degraded materials, proving that the considered wastewaters present a good energetic potential.

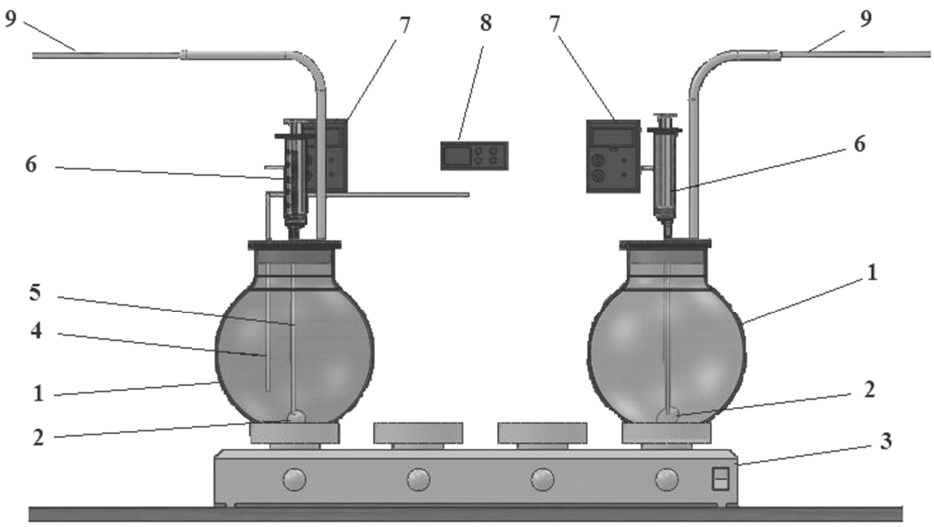

Figure 1. Overall view of the small-scale installation

TABLE 1. Physicochemical properties of raw materials used for anaerobic digestion process

Biomass	Barley	Rye	Wastewater from treatment plant	Wastewater from beer factory
Moisture content (db) [%]	10.5	10.2	5.8	5
Ash content (db) [%]	2.5	1.65	36	26.5
Net calorific value (db)[J/g]	17300	17300	14100	16000
Carbon content[%]	40.4	40.5	32.1	36.5
Nitrogen content [%]	1.45	1.5	5.1	7.1
Volatile matter content (db) [%]	82.7	84.5	37.7	42.5

The evolution of pH during digestion process is presented in figure 2 From the figure it can be observed that the substrates prepared with wastewater from beer factory had an initial pH around 4.5. The time to reach a pH greater than 6 was around 15 days. The mixture between barley and wastewater from treatment plant was the most constant one from the pH point of view, while the mixture between rye and wastewater from treatment plant had a slightly alkaline tendency at the beginning.

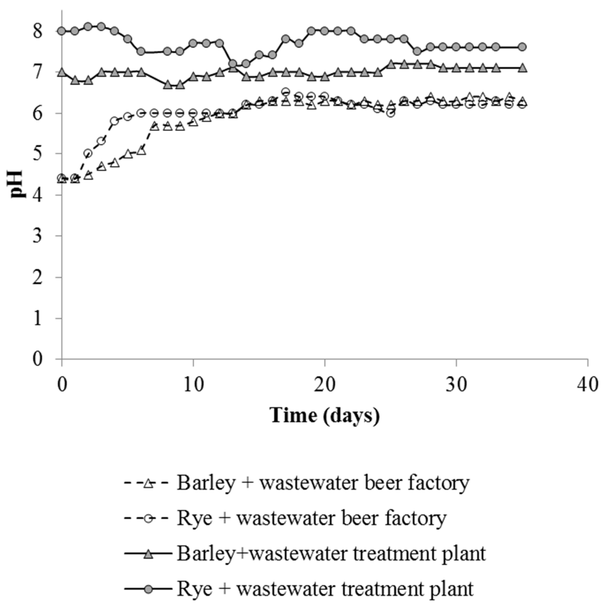

Figure 2. pH variation during digestion process

The quantities of biogas produced by anaerobic digestion are presented in figure 3.

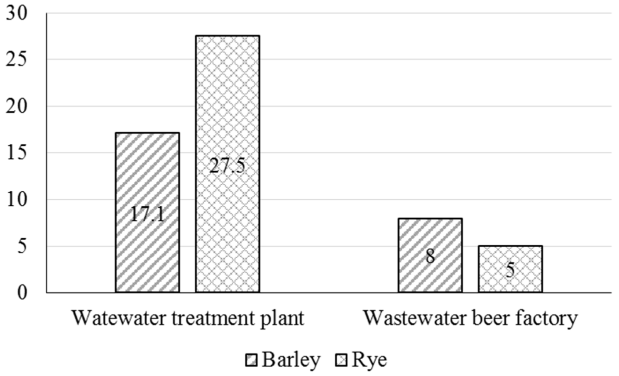

Figure 3. Biogas produced by anaerobic digestion

The results presented in figure 3 revealed that the substrates prepared with wastewater from treatment plant are more suitable for an anaerobic digestion process. The quantities of biogas produced are considerable higher in the case of substrates prepared with wastewater from treatment plant than in the case of those prepared with wastewater from beer factory. As concern the two agricultural biomasses, the mix formed by rye and wastewater from treatment plant had the highest production of biogas. The production was 5.5 times lower when the rye is mixed with wastewater from beer factory.

During the tests, the composition in CH_4 and CO_2 of biogas was measured. The CH_4 and CO_2 concentrations are presented in figures 4 and 5.

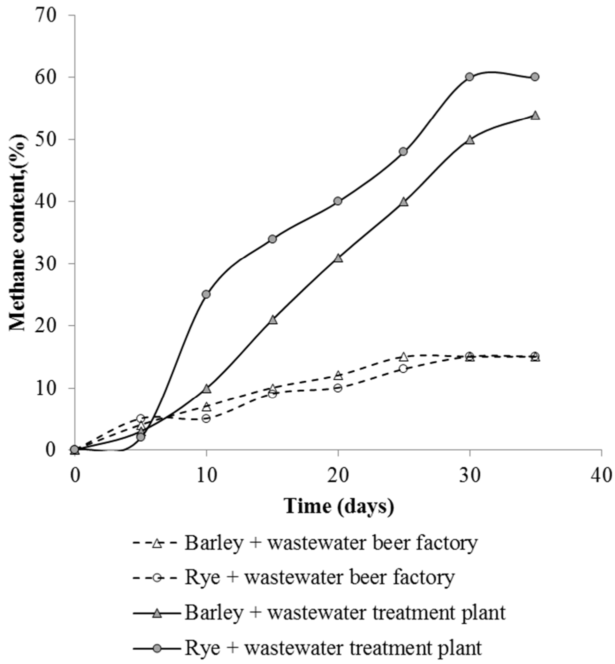

Figure 4. Concentrations of CH_4 in the biogas produced by anaerobic digestion

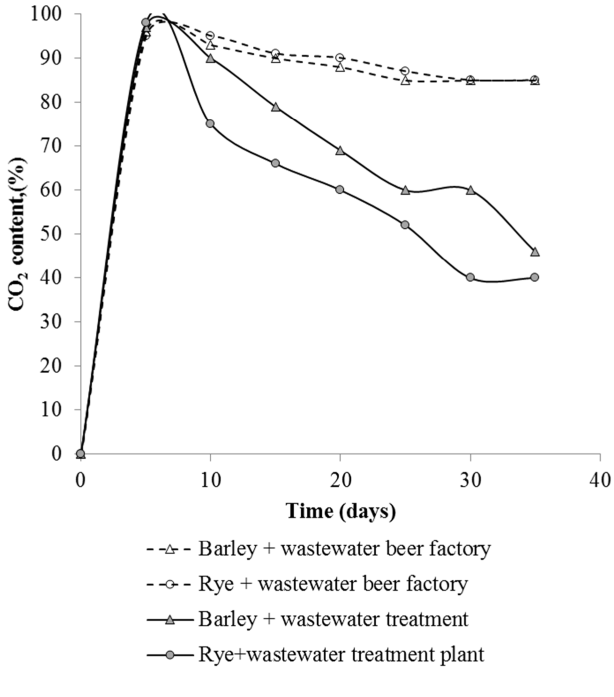

Figure 5. Concentrations of CO_2 in the biogas produced by anaerobic digestion

TABLE 2. Physicochemical properties of digestates

Biomass	Barley + wastewater from treatment plant	Rye + wastewater from treatment plant	Barley + wastewater from beer factory	Rye + wastewater from beer factory
Moisture content (db) [%]	3.66	1.87	1.96	1.53
Ash content (db) [%]	14.2	10.8	3.44	3.97
Net calorific value (db)[J/g]	16199	16541	18040	16600
Carbon content[%]	43.8	44.5	48.7	47.3
Nitrogen content [%]	1.95	6.41	1.07	1.64
Volatile matter content (db) [%]	70.4	72.4	80.0	78.86

From figure 4 it can be observed that the methane concentration in biogas is significant higher for substrates prepared with wastewater from treatment plant (60 % for substrate based on rye and 54 % for substrate based on barley). The methane content in the biogas from anaerobic digestion of substrates prepared with wastewater from beer factory reach only 15 %. This value is inappropriate for further exploitation of biogas.

According to figure 5, the CO_2 values indicate different behavior depending on the type of wastewater used. The highest value for CO_2 was obtained for the batches with wastewater from beer factory (85% by volume), while the batches with wastewater from treatment plant had a minimum of 40% for rye and 46% for barley.

In all cases the biogas content in CO_2 is high, which makes biogas unusable in combustion processes.

The residues from the digestion process were analyzed from physico-chemical point of view and the results are presented in Table 2.

From the table above, one can observe that after the process the mixture of degraded cereals with treatment plant wastewater present a high ash content making them unusable inside firing or even cofiring processes. The calorific value decreased with a low value, which is an indicator that during this process the materials were not capitalized to their maximum value.

4. Conclusions

The results of the present study revealed that all the tested degraded materials present a better behavior during anaerobic fermentation with wastewater from treatment plant. This makes this type of water more suitable, at least at this level, for further testing, even if research still has to be continued in order to determine the best combinations between wastewater from beer factory and other degraded materials.

It can be determined that the ash content for the resulting materials after the process in combination with wastewater from treatment plant presents high values and this indicates that it cannot be used in further firing processes. The calorific values after the process by comparison with the ones before the process show that in combination with wastewater from treatment plant, the degraded cereal types are better capitalized using this type of process.

The influence of the C/N ratio is to be taken into consideration but for both processes the anaerobic fermentation took place in relatively good conditions with suitable results that imply for the need to continue inside finding better combinations of materials and to further test the existing recipes at larger scale, if possible to fully understand the material behavior during anaerobic fermentation.

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