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BIOGAS PRODUCTION USING WASTE WATERS – INFLUENCE OF PROCESS PARAMETERS FOR TEST RIG AT LABORATORY SCALE

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ABSTRACT. Biogas production by anaerobic digestion of residual waters from different sources (a treatment plant and a beer factory) was investigated in laboratory small scale batch reactors. Both wastewaters represent efficient biogas substrates. As concern the methane composition, the value is slightly higher in the case of biogas produced by anaerobic digestion of wastewater from beer factory. In the second part of this study, anaerobic co-digestion of wastewater and cow whey was performed. Addition of cow whey to wastewater from beer factory increase the biogas yield, while the addition of cow whey to wastewater from treatment plant decrease the biogas yield. In both cases of co-digestion, the methane content in biogas was higher than in the single digestion processes.

Keywords: *wastewater, anaerobic digestion, biogas, methane yield*

INTRODUCTION

The rapid development of human society increased the energy demands, which will lead to the depletion of conventional energy sources [1].

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Meanwhile, in the world, huge amounts of wastewater coming from agriculture, industry or domestic activities are generated. The composition of these wastewaters depends on the source and its characteristics, but the main constituents are: organic matter, nutrients (nitrogen, phosphorus and potassium), inorganic matter (dissolved minerals), toxic chemicals and pathogens [2]. Releasing of an untreated wastewater effluent into environment can have negative impact on ecosystem and human health. Now, there are a variety of strategies used to treat the wastewaters [3,4]

Anaerobic digestion is an interesting solution to this problem which leads to biogas and digestate [5]. The biogas is generally composed of ca. 48–65% methane, ca. 36–41% carbon dioxide, up to 17% nitrogen, <1% oxygen and traces of hydrogen sulphide or other gases [6]. The process works at cryophilic, mesophilic (25–37°C) and thermophilic (45–55°C) temperatures.

According to literature, higher biogas quantities were obtained in the case of wastewater co-fermentation with percentages of other residual materials from dairy industry, sugar industry, brewery industry [7-9].

The dairy industry is divided into several sectors, which are associated to the production of contaminated wastewaters. These effluents have different characteristics, according to the product obtained (yogurt, cheese, butter, milk, ice cream, etc.). Moreover, the wastewater management, climate, operating conditions and types of cleaning-in-place, also influence the dairy effluents characterization [10]. The dairy effluents show a relatively high organic load, monitored by biological oxygen demand (BOD) and chemical oxygen demand (COD) in the range of 0.1-100 kg/m^3 with an index of biodegradability (BOD5/COD) typically in the range 0.4 - 0.8. Organic matter content is mainly due to the presence of milk carbohydrates and proteins such as lactose and casein, respectively [11].

The composition of whey resulting from the white cheese making process is presented in table 1.

Table 1. Constituents of whey resulting from white cheese making process [12]

Constituent	Percentage, [%]
Water	94
Protein	0.8 – 1.0
Lactose	4.5 – 5.0
Fat	<0.1
Minerals	<0.1
pH	4.5 - 5

From a wastewater treatment point of view, anaerobic digestion of cheese whey offers an excellent approach. However, raw whey is known to be quite problematic to be treated anaerobically, because of its low bicarbonate alkalinity, high COD concentration and its tendency to get acidified very rapidly [13]. Supplemental alkalinity is required so as to avoid acidification and subsequently anaerobic process failure [14].

By comparison with other types of biomass, whey general properties are presented in Table 2 [15].

Table 2. Comparative properties of whey with other biomass types

Biomass	pH	TS, [%]	VS, [% TS]	TN, [% TS]
Tomato skin and seeds	4.7	32.0	97.8	3.34
Barley straw	7.87	90.5	94.3	0.99
Rice straw	8.14	88.7	91.9	0.88
Grape stalks	4.4	31.1	91.9	1.99
Maize drying up residues	5.05	81.8	97.5	1.29
Whey	5.2	6.86	91.1	1.83
Grape marcs	3.58	61.4	90.7	2.30
Inoculum	8.00	7.62	70.0	5.93

where: TS - total solids, VS - volatile solids, TN - total nitrogen.

The protein profile of whey is presented in Table 3.

Table 3. Protein profile of whey and primary structure basic properties [16]

Protein	Concentration, [g/L]	Molecular weight, [kDa]	Number of amino acids residues
β-Lactoglobulin	1.3	18.277	162
α-Lactalbumin	1.2	14.175	123
Bovine serum albumin	0.4	66.267	582
Immunoglobulins (A, M and C)	07	25000 (light chain) + 50000 (heavy chain)	-
Lactoferrin	0.1	80000	700
Lactoperoxidase	0.03	70000	612
Glycomacropetide	1.2	6700	64

As it can be observed, this material can be used in co fermentation processes in order to produce biogas.

This work evaluates the feasibility of anaerobic digestion of two wastewater types from a treatment plant and from a beer factory. For this purpose, laboratory experiments were conducted. The performance of the reactor was monitored and evaluated in terms of pH, methane content, carbon dioxide content and biogas production. In addition, the anaerobic fermentation efficiency of wastewaters co-fermented with cow whey was also evaluated.

RESULTS AND DISCUSSION

The small scale anaerobic installation was used to test the digestion performances of residual waters from water treatment plant and beer factory and, also the combination between those two materials and cow whey (90% waste waters and 10% cow whey).

The time variation for pH is presented in figure 1. In the figure it can be observed that during the fermentation process, the pH in the reactor containing only wastewater from the beer factory (WW2) was relatively stable with values in the range of 6.5 – 7. The co-fermented material (WW2+CW) presented a pH variation between 6 and 6.8 due to acid influences of the cow whey inside the first period of the process. The pH during the fermentation process of wastewater from treatment plant (WW1) had an initial acid tendency, but after corrections the values raised slowly from 6.1 to 7.1 at the end of the process. The co-fermented batch (WW1+CW) had at the beginning of the process an oscillated pH around 6. After correction it was raised at 7.5 – 7.7 and remained constant along the study.

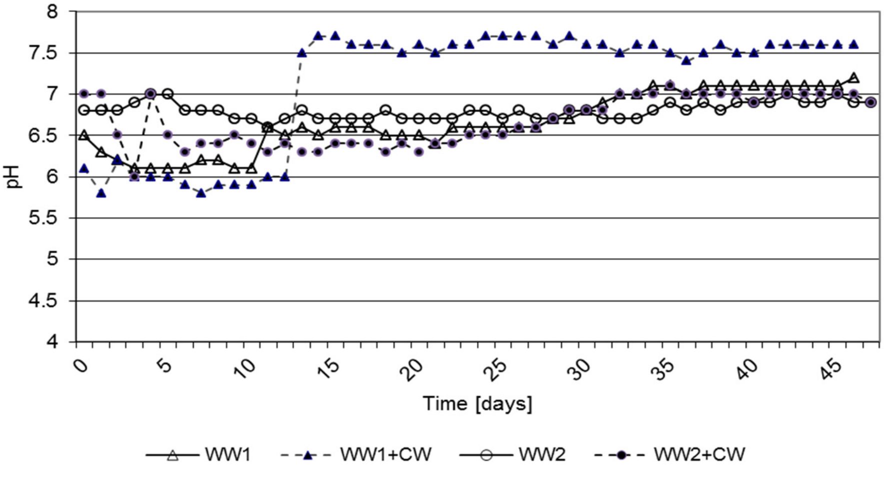

Figure 1. pH variation for the studied batch

During the anaerobic digestion process the following parameters were monitored: the total quantity of biogas produced and its partial composition (in terms of CH_4 and CO_2 concentrations).

The total quantity of biogas produced at the end of each anaerobic fermentation process is presented in figure 2.

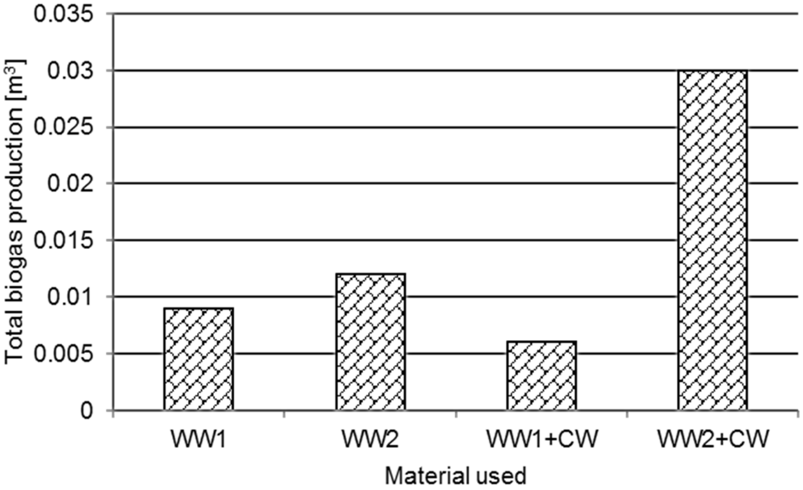

Figure 2. Total biogas produced in the case of each material used

The figure revealed that the addition of cow whey to wastewater from beer factory increased the production of biogas by 2.5 times, while the same addition to the wastewater from treatment plant inhibited partially the anaerobic digestion process. Total biogas production was found in the order: 90% wastewater from bear factory + 10% cow whey (0.03 m^3) > wastewater from bear factory (0.012 m^3) > wastewater from treatment plant (0.009 m^3) > 90% wastewater from treatment plant + 10% cow whey (0.006 m^3).

According to literature [23,24], the biogas and methane production efficiency is influenced by the total solids (TS) content of the substrate used in the anaerobic digestion process. In our study the TS content of the substrates investigated is around 2% for WW1, 2.4% for WW1+CW, 3% for WW2 and 3.5 % for WW2+CW. The quantity of biogas produced by anaerobic digestion increase with the increasing of TS content. Exception was the co-substrate wastewater from treatment plant and cow whey which generated an unusual low quantity of biogas. The anomaly can arise from the fact that, in this situation, the cow whey partially inhibited the biogas production process due to lack of a previous environment adapted for co-fermentation of wastewater with cow whey.

In the next step of the study, the quality of biogas was evaluated. In this purpose, the methane and carbon dioxide composition was evaluated.

The CH_4 composition of biogas for the four studied substrates is presented in figure 3.

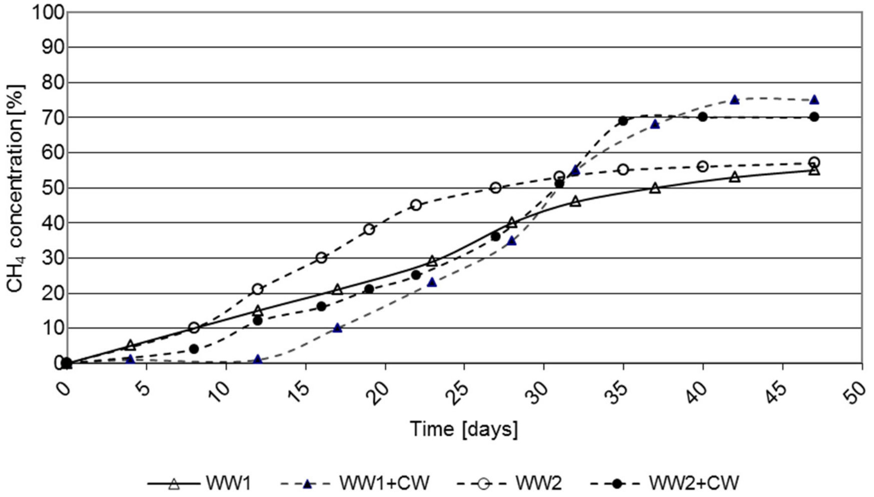

Figure 3. Evolution of CH_4 concentration during anaerobic digestion of studied batch

The methane concentration showed an increasing trend over time for all the studied situations. In the first 30 days of the process, the methane quantity is higher in the biogas produced from WW1 and WW2. After 30 days, the concentration of methane became higher in the biogas generated by anaerobic digestion of wastewaters co-fermented with cow whey. A maximum of 55% and 57% methane was reached during wastewater WW1 and WW2 fermentation, while the maximum methane production for co-fermented material WW1+CW was 75 % and for WW2+CW was 70 %.

The CO_2 composition of biogas for the four studied substrates is presented in figure 4.

The CO_2 concentration in the biogas varies between 40% and 20% for the wastewater WW1 and between 50% and 35% for the wastewater WW2. The co-fermented batches show higher CO_2 concentrations in the first 30 days and, in the end of the process the concentration decrease in the range 25 - 30%.

Relative to the residence time of materials inside the anaerobic fermenters, the experiment was made using a stationary batch type reactor, in this case the total residence time for the used materials being equal to the period of time of the experiment (approximately 47 days). WW1 and WW2 batches started to produce methane after 24-48 hours of process, in small concentrations, while the process of methane production was slow for the other two batches – between 5 and 12 days.

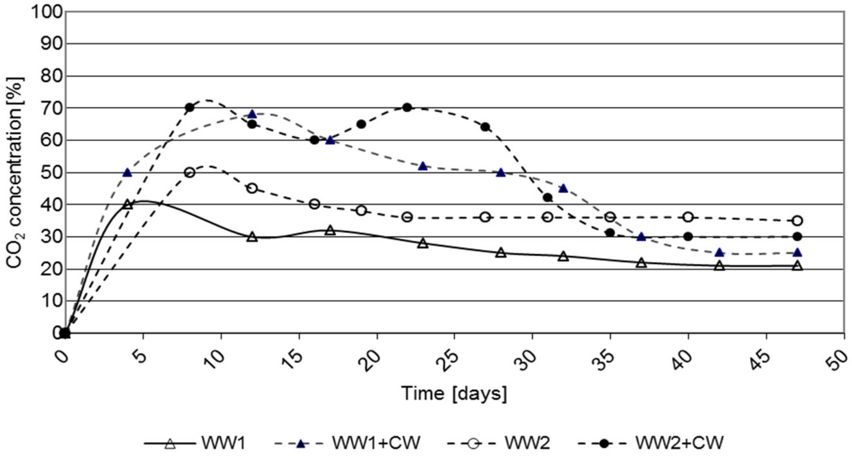

Figure 4. Evolution of CO_2 concentration during anaerobic digestion of studied batch

The overall efficiency of the process was relatively low for the WW1 and WW2 batches in terms of quality for the obtained biogas, and relatively high for the other two studied batches, showing an improvement over the biogas quality – high percentage in methane. This aspect is a key factor in terms of further using the produced biofuel inside firing processes.

The higher quantity of biogas was exhibit by the mix of 90% wastewater from beer factory and 10% cow whey but the wastewater from beer factory had better results in terms of biogas quality over time.

CONCLUSIONS

Anaerobic digestion of wastewaters from a treatment plant and a beer factory was performed in laboratory batch reactors during 47 days. The feasibility of the anaerobic co-digestion of mixed residual water and cow whey was also investigated.

Single substrate digestion of wastewaters showed higher biogas production for residual water coming from treatment plant. Addition of cow whey to wastewater from beer factory increases the production of biogas, while addition to wastewater from treatment plant decreases the biogas production. In the meantime, the co-digestion process increases the concentration of methane in biogas for both case studies.

The results showed potential for all materials, with accent on combinations between residual waters and cow whey, both in terms of results and way of process control.

EXPERIMENTAL SECTION

1. Characteristics of wastewaters

The studied wastewaters were collected from a water treatment plant located in Timisoara City (WW1) and from a beer factory (WW2). The characteristics of these materials were determined according to the procedures of the standard methods [17-22] and are presented in table 4. All analyses were performed in duplicate and the results were expressed as mean values.

Table 4. General characteristics of wastewater

	WW1	WW2
Measured parameter	Value	Value
Carbon content, [%]	32	36.4
Sulphur content, [%]	5.1	4.4
Chlorine content, [mg/kg]	1.1	2.7
Volatile content (dry basis), [%]	37.9	42.3
Hygroscopic moisture content, [%]	5.85	5.1
Ash content (dry basis), [%]	36.2	26.7
Mean calorific value (dry basis), [MJ/kg]	15.2	17.4

As it can be observed from the table above, the carbon content is relatively high, close to the range specific to agricultural waste materials (40 – 45%). The sulphur and chlorine content show that the used materials cannot be used inside firing processes, at least not alone, because of the risk to affect the combustion chamber negatively – there is a high possibility of forming acid components during oxidizing process. Even if the mean calorific value for the wastewaters shows increased energetic potential in terms of capitalization, the ash content is very high, proving to be not fit to be used in any type of firing or co-firing processes. The resulting residual quantity is to high, rising the problem of properly managing the obtained waste material.

In a second study, the wastewaters were co-fermented with cow whey (CW). The percentage of cow whey was 10% of the total suspension volume inside the fermentation tanks.

2. Experimental set-up

Two laboratory scale anaerobic reactors with a total volume of 6L were used in this study.

The schematic of the experimental set-up is presented in figure 5.

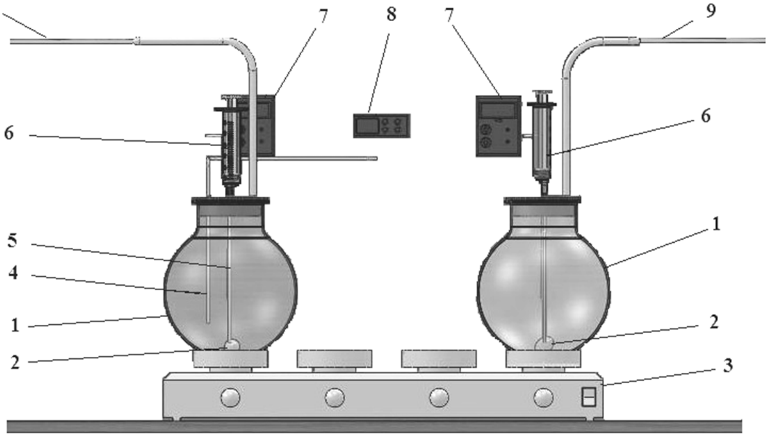

Figure 5. Schematic experimental setup

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

In order to obtain a good fermentation process the glass reactors used for anaerobe fermentation were covered with a layer of black paint.

The fermentation process was held for 47 days in order to observe the pH, the biogas yield and its composition in terms of CH_4 and CO_2 concentration. The temperature was kept constant in a range between 36 and 37 °C. In order to correct the pH values during the process, it was used a solution of NH_3, 10% concentration.

For measuring the methane and carbon dioxide concentration of biogas a DELTA 1600 S IV gas analyzer was used.

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