Efficiency Assessment of the Anaerobic Digestion of Sewage Sludge from Timisoara Municipal Water Treatment Plant

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The sewage sludge is a residual, redundant product resulting from the treatment of wastewater in municipal treatment plants (WWTP). Stabilization by means of anaerobic digestion represents state of art of the treating process. Input parameters of the digestion process are the volume flows of the raw or biological sludge, or sludge and co-substrates as appropriate, and the output parameters of the process are the volumes of digested sludge, digestate and biogas, products resulting from the digestion process. Besides the fact that the anaerobic digestion is one necessary process to ensure sludge treatment, the WWTP operators must manage the process in such a manner so that it may be feasible and efficient, regarding energy efficiency. The purpose of this paper is to evaluate the digestion process efficiency, by specific production of biogas and demonstrating that it is possible to turn waste into energy.

Keywords: sewage sludge, anaerobic digestion, biogas, sludge treatment, process efficiency.

According to Romanian legislation aligned with the European one, the sewage sludge is classified as waste, even more, a dangerous hazardous waste, if it is not properly treated before being discharged from the treatment plant, not mentioning the risk of not being accepted for storage [1, 2]. One of the most important step of the treating sludge line is the stabilization process that occurs by means of anaerobic digestion, in specially units, constructed for this purpose [3, 4].

Stabilization by means of anaerobic digestion represents state of art of the treating process. Input parameters of the digestion process are (i) the volume flows of the raw or biological sludge, (ii) sludge and co-substrates as appropriate. The output parameters of the process are the (i) volumes of digested sludge, (ii) quantity of digestate and (iii) biogas volumes, all products resulting from the digestion process [5]. The sludge treatment is considered effective if the energy recovered through the produced biogas combustion can cover the technological energy consumption that ensures the entire development of the process [6-8].

The anaerobic digestion process (ADP) of sewage sludge is a biological degradation process of organic material in the absence of free molecular oxygen (O_2) by means of the anaerobes bacteria present in the sludge. The process provides volume and mass reduction and delivers valuable renewable energy by the produced biogas [9].

The anaerobic stabilization is a slow process that results in the breakdown of particulate material and macromolecules from sewage sludge in four key stages as follows: (1) hydrolysis, (2) acidogenesis, (3) acetogenesis and (4) methanogenesis [9]. The most important stages in terms of the production of methane are the third and fourth stages, within activities of the two key bacterial acetogens and methanogens groups are generating the biogas production [10].

Biogas consists mostly of methane (CH_4) and carbon dioxide (CO_2). The majority of methane produced in an anaerobic digester occurs from the use of acetate and hydrogen by support of the methane-forming bacteria. The fermentation of substrates such as acetate results in the production of methane (equation 1), and the reduction of carbon dioxide is also present in the production of methane (equation 2) [10].

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (1)$$
$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (2)$$

Anaerobic digestion systems can be designed to operate in a number of different configurations, specificities being indicated as follows [9]:
- batch or continuous;
- temperature controlled: Mesophilic or thermophilic;
- solids content: High solids or low solids;
- complexity: Single stage versus multistage.

Experimental part

For the carried out experiments the material used (excess activated sludge) was collected from the Timisoara municipal WWTP. The treating processes for the wastewater and sewage sludge schemes are shown in figure 1.

According to figure 1 it can be observed that, in the wastewater treatment process a primary settling is missing, therefore there is no primary sludge. As result an important source of organic matter, required for digestion process, is lost. Therefore the achieved study is important, because, even if it represents a special individual case, the result indicates a potential efficient use of available energy through bio-gas production.

Applying repeated laboratory analysis [12, 13] of the excess activated sludge, regarding the moisture content and its loss by calcination, one found that volatile solids (VS) content is greater than 50 % by mass, the annual

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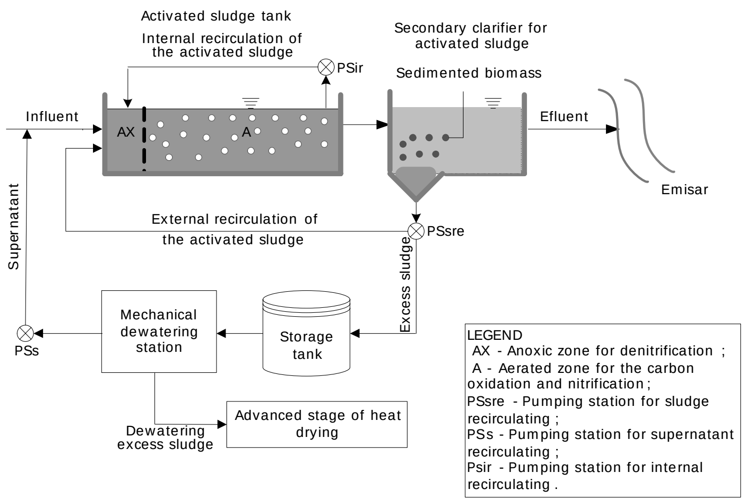

Fig. 1. Schematic process flow of waste water and sewage sludge treatment, for the Timisoara municipal WWTP

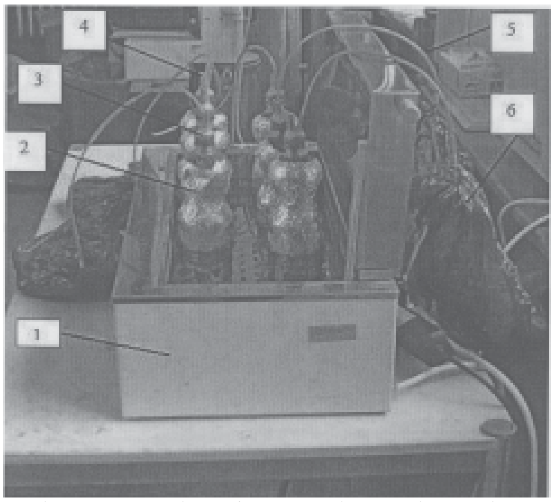

Fig. 2. Overall view of the experimental installation for assessment of the efficiency of the fermentation.

average for 2013 being of 64.54 %. Therefore a great interest for the excess sludge stabilization, by anaerobic digestion, exists [8].

In order to assess the efficiency of fermentation, one started with the idea of determining the specific production of biogas - q_{bg} [8] for sludge originated from the Timisoara municipal WWTP, using a laboratory experimental installation, which is presented in figure 2.

The components are described as follows:

– thermostatic bath with 6 places for heating up the used materials for the anaerobic fermentation process (the temperature is controlled with the help of the thermocouple and can be checked with the help of a thermometer inserted into the bath);

– plastic vessels with a total volume of two liters, filled up with about 1.5 L of the materials used for determinations;

- the corks of the vessels were modified in order to allow both sampling for pH checking, homogenization by means of syringes, and the gas transfer from the recipients into the gas bags. Also, because of the light sensibility of the anaerobic bacteria, the vessels were covered with aluminum foil;

- hose orifice for syringe insertion, used for sampling and homogenization;

- connection (small diameter hose) between the plastic bottle and the gas bag for biogas storage;

- gas bag for biogas storage.

Description of the experiment development

Preparation of the sludge batch subject to fermentation

To achieve a humidity around 5% by mass [11] for the sludge batch to be fermented, a mixture was formed between two co-substrates, namely, the excess biological activated sludge, coming from the storage tank, and the sludge from the mechanical dewatering station (fig. 1).

The calculation procedure for the volume of a co-substrate for a mixture of substrates with different moisture contents, to achieve required moisture of mixture (about 95 %), as a determinant factor for an efficient digestion, is based on formula (3):

$$V_{cs_1} = \frac{V_{am} \times \gamma_{cs_1} \times (W_{am} - W_{cs_2})}{\gamma_{cs_1} \times (W_{cs_1} - W_{am}) + \gamma_{cs_2} \times (W_{am} - W_{cs_2})} \quad (3)$$

where:

V_{cs1} is the substrate volume “wetter” [liters];

V_{am} – mixture volume [liters];

Y_{cs1} and Y_{cs2} – specific gravity of wet substrate from mixture [t/m^3];

W_{am}, W_{cs1} and V_{cs2} – mixture and co-substrates moisture [% by mass].

The formula (3) is original, starting from the sludge moisture formula.

Calculation for the specific gravity of a co-substrate (sludge) - γ_{cs} is given by formula (4):

$$\gamma_{cs} = \frac{\gamma_a \times \gamma_{cs_{dry}}}{\gamma_a + \frac{W_{cs}}{100}\left(\gamma_{cs_{dry}} - \gamma_a\right)} \quad (4)$$

where:

γ_a is the Specific gravity of wastewater from sludge [t/m^3];

γ_{csdry} – specific gravity of solids from sludge [t/m^3];

W_{cs} – sludge moisture content [% by mass].

The amount of wet co-substrate used in mixture (V_{cs1}) is calculated according to formula (3), in which all needed parameters are known, as follows:

V_{am} - value selected, depending on the volume of mixture required for experiments, in the considered case – 2L;

Y_{cs1} and Y_{cs2} - calculated according to the formula (4);

W_{am} – selected according to the configuration of anaerobic digestion systems can be designed to operate, in this case – 95 %;

W_{cs1} and W_{cs2} - values determined through laboratory analyzes.

The process configuration regarding the feedstock supply

Taking into account the absence of primary sludge from the mixture of co-substrates introduced into the digestion

Co-substrate	Sludge moisture content	The specific gravity of solids from sludge	The specific gravity of wet co-substrates
	% by mas	t/m^3	t/m^3
Excess activated sludge from storage tanks - CS1	99	1.3	1.0023
Excess activated sludge from dewatering station - CS2	80	1.3	1.0484

Table 1
PHYSICAL CHARACTERISTICS OF CO-SUBSTRATES

The mixture prepared in order to perform the experiments	Component parts of the mixture	The moisture content of the mixture [% by mass]	Amount of substrates in the mixture	The volume of the mixture [liters]	pH of the mixture
LOT 1	CS1	95	1.60 liters	2.00	7.1
	CS2		0.425 kg		

Table 2
PHYSICAL CHARACTERISTICS AND THE AMOUNTS OF CO-SUBSTRATES FROM MIXTURE

process and the low level of putrefaction for biological activated sludge, one has chosen a constant supply of the fermenter, with raw (fresh) sludge, in daily stages [9].

To ensure a good development of the digestion process and to and avoid an acid digestion, it is necessary to create a permanent contact between fresh sludge and fermented sludge. In this respect, the fresh sludge must be permanently mixed with the older digested sludge, to equalize the quality of sludge in the recipient and to put the mature anaerobic bacteria from the old, well digested sludge, into contact with the fresh sludge [7].

In order to ensure the digestion of sludge and therefore the mature bacteria necessary for the development of digestion process, in the first 15 days, the fermentation was hold in a batch system, in the simplest form. Finally the sludge was added to the reactor at the beginning and sealed for the duration of the process.

After this period we switched the experiment, to a continuous process, in which, fresh sludge was continuously added in digester, in daily stages. Every day has been introduced in digestion process, an amount of fresh sludge, around to 10% from the net volume of the fermenter, approximately 150 mL. Of course that at the same time, an equal part of fermented sludge, had to be eliminated from digester. Therefore could be determined the amount of biodegradable organic matter, reduced by digestion process.

Periodically, during the experiment, was measured the amount of biogas produced in the fermentation process. During the whole time of the fermentation process, was maintained one mesophilic temperature regime, and the *p*H of the mixture was monitored.

Results and discussions

In this paragraph are shown in tabular and graphical form, the results obtained after calculations and experiments, according to those presented in the paragraph 2.

In tables 1 and 2 are shown the physico-chemical characteristics of the sludge co-substrates and mixture, and the amounts of co-substrates and mixture used in the experimental process.

In figure 3 are shown the amounts of switched sludge in continuous digestion process. It can be observed that every day, approximately 150 g which represents about 10% by mass of all existing sludge in the fermenter fermented sludge was removed from the fermenter. Of course, in order

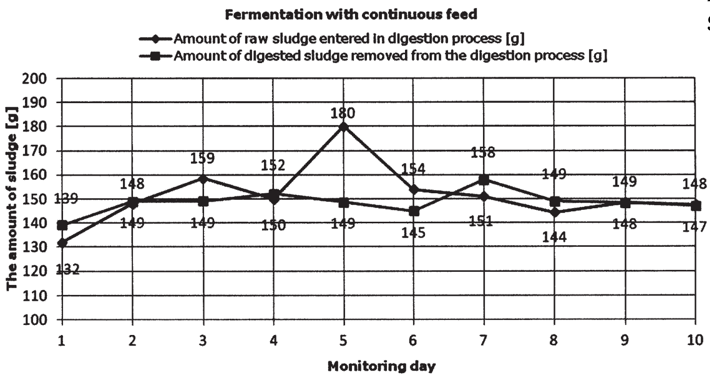

Fig. 3. Amounts of entered/removed sludge in/from digestion process.

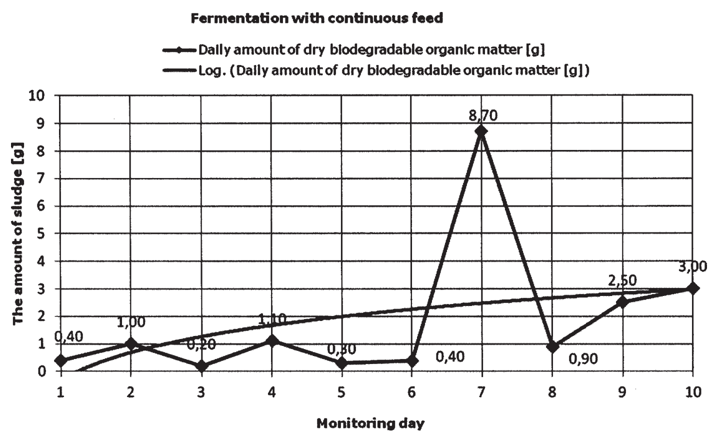

Fig. 4. Daily amounts of reduced sludge, during digestion process.

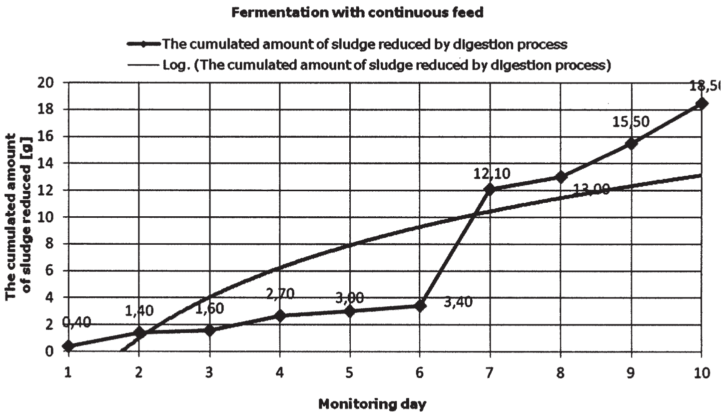

Fig. 5. Cumulated amounts of reduced volatile matter, from sludge, during digestion process.

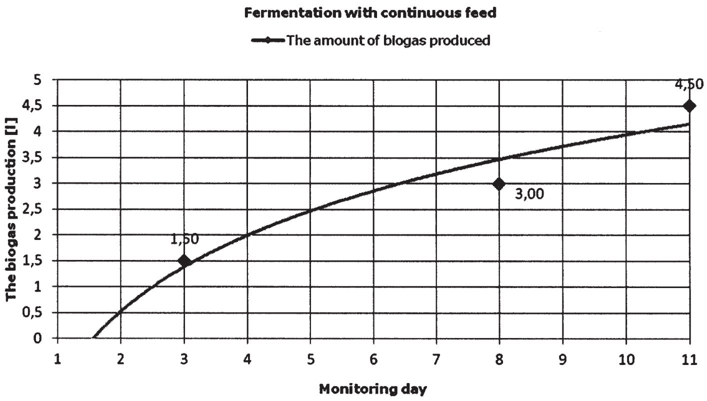

Fig. 6. Biogas cumulated production, during digestion process

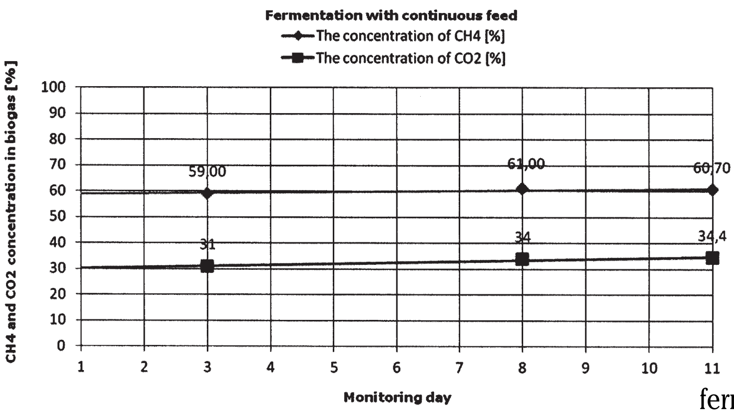

Fig. 7. Concentration of the main components, in the obtained biogas

to maintain the digestion process, an amount approximately equal to the fresh sludge was introduced in the digestion process. A percentage of 10 % was chosen taking into account the experience of good practice for running sludge digestion process, according to the operators from Straubing WWTP (Germany).

In figures 4 and 5 are shown the amounts of reduced sludge (daily and cumulated), obtained in a continuous digestion process. It can be observed that the amount of organic matter reduced daily by bacterial fermentation activity has an increasing trend according to a specific (logarithmic) shape, which indicates an increase in bacterial activity during the process of digestion [6, 7].

In figure 6 are shown the cumulated amounts of biogas produced by digestion process. It can be observed that the evolution of the accumulated amounts of biogas is faster than the evolution of the cumulative amounts of organic matter reduced. This is explained by the kinetic model to increase biogas production, by increasing the mass of acetogens and methanogens bacterial groups [7].

In figure 7 are shown the concentrations of the main components in the obtained biogas. It can be observed that the concentration of methane in the biogas composition at the end of the monitoring period for the fermentation process is over 60 % from the starting value, which indicates a proper development of the digestion process [6-8]. Also the proportion of secondary undesired components in the biogas composition is low, less than 5 %.

In figure 8 the *p*H evolution during the digestion process is shown. From this figure it can be seen that the *p*H during the fermentation process remains approximately constant at around 7.3, thus providing a favorable environment for bacterial growth.

To evaluate the efficiency of fermentation, measured by specific production of biogas - q_{bg}, the cumulative amount of biogas produced during the fermentation process V_{bg}, and the amount of volatile matter from the mixture of co-substrates, reduced during the digestion process - m_{VSrad} [8] must be known.

One obtained according with the figure 6 V_{bg} = 4.50 liters and according to figure 5 m_{VSrad} = 18.5 g. As result it follows that:

$$q_{bg} = \frac{V_{bg}}{m_{VS_{red}}} \left[\frac{m^3 \text{biogas}}{\text{kg reduced volatile solids}}\right]$$

$$q_{bg} = 0.24 \left[\frac{m^3 \text{biogas}}{\text{kg reduced volatile solids}}\right] \qquad (5)$$

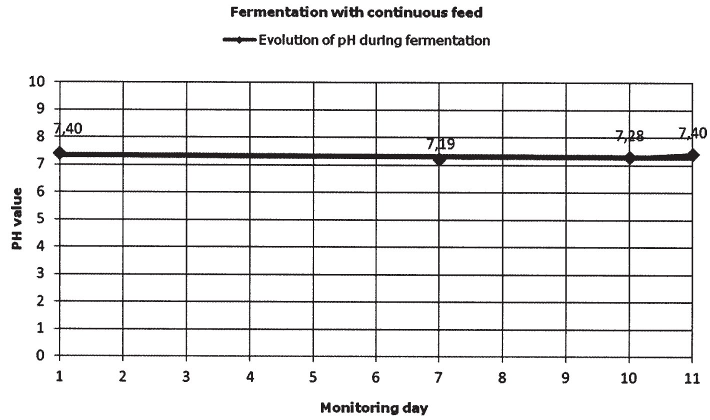

Fig. 8. *p*H evolution during digestion process

Considering that from the mixture of sludge the primary sludge is missing, and that no co-substrates were used for co-fermentation, the achieved biogas production might be considered fully acceptable in comparison with data from the specific literature, that indicates, for an usually anaerobic fermentation tank, supplied with primary and excess activated sludge, a biogas production of about 0.5 to 0.8 m^3 biogas/kg reduced volatile solids [8].

Conclusions

This article presents an experimental method of proving the anaerobic digestion efficiency for a waste with one biodegradable organic load, that is able to generate a corresponding potential for biogas production. The method consists in calculation of the specific biogas production, according to data based on experimental determination of the amounts of biogas and biodegradable organic matter, and by means of a small laboratory plant.

In the article presented, the focus was on how to prepare a mixture of co-substrates, for obtaining one certain moisture, which is one of the determinants of the fermentation efficiency. In the case study presented in this article, excess biological activated sludge from Timisoara municipal WWTP is chosen as the biodegradable organic material. With the aid of a mixing prescription, one succeeded in preparing a mixture of sludge, having an imposed humidity (selected value). This procedure is based on mathematical formulae, in which the humidity of sludge and the volume of the mixture, physical characteristics which can be accurately determined, by laboratory analyzes are the input parameters.

Chosen method provides an accurate assessment of the anaerobic fermentation efficiency, by determining the biogas specific production, for mixtures of biodegradable organic co-substrates. The advantage of presented method is that, all parameters can be accurately determined or measured, being not used variables, or coefficients, that provide sometimes, approximate results.

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References

1.*** Ministerul Mediului şi Gospodăriri Apelor, ORDIN nr. 95 din 12 februarie 2005, privind stabilirea criteriilor de acceptare şi procedurilor preliminare de acceptare a deşeurilor la depozitare şi lista natională de deşeuri acceptate în fiecare clasă de depozit de deşeuri, Monitorul Oficial nr. 194 din 8 martie 2005;

2.*** Guvernul României, OUG nr. 78 din 16 iunie 2000, actualizată, privind regimul deşeurilor, Monitorul Oficial nr. 283 din 22 iunie 2000;

3.NEAMŢ,I., IONEL,I., FLORESCU, C., Rev. Chim. (Bucharest), **63**, no. 7, 2012, p. 739

4.MACHNICKA, A., SUSCHKA, J., GRÜBEL, K., The intensification of sewage sludge anaerobic digestion by partial disintegration of surplus activated sludge and foam, „Integration and Optimization of sanitation Systems in Urban Areas: proceedings of Polish-Swedish seminars", Cracow, March 17-18, 2005, Pg. 87-93;

5. NEAMT, I., IONEL, I., VLAICU, I., The mass balance of sewage sludge digestion process, Proc. 38th Annual Congress of ARA, Los Angeles 2014, Pg. 107-114;

6.NEGULESCU, M.,Tratarea apelor uzate municipale, Editura Tehnică, Bucuresti, Romania-1978;

7.NEGULESCU, M., Municipal Waste Water Treatment, In: Developments in Water Science, ELSEVIER SCIENCE PUBLISHERS, New York and Amsterdam, Technical Press, Bucharest, Romania-1985;

8.*** Ministerul Dezvoltării Regionale şi Administraţiei Publice, ORDIN nr. 2.901 din 4 septembrie 2013, pentru aprobarea reglementării tehnice "Normativ privind proiectarea, execuţia şi exploatarea sistemelor de alimentare cu apă şi canalizare a localităţilor. Indicativ NP 133-2013", Monitorul Oficial nr. 660 din 28 octombrie 2013;

9.*** http://www.bioenergywiki.net/Anaerobic, accessed by June 2014;

10.GERARDI, M.H., The Microbiology of Anaerobic Digesters, ISBN 0-471-20693-8, New Jersey, US: Wiley-Interscience. 2003. 192 p;

11.ZUPANČIČ, G.D., GRILC, V.,Anaerobic Treatment and Biogas Production from Organic Waste, Institute for Environmental Protection and Sensors Slovenia, Environmental Engineering » "Management of Organic Waste", book edited by Sunil Kumar and Ajay Bharti, ISBN 978-953-307-925-7, Published: February 1, 2012 under CC BY 3.0 license;

12.*** EN 14774 – Solid bio-fuels – Determination of moisture content – Oven dry method;

13.*** EN 15148 – Solid bio-fuels – Determination of the content of volatile matter

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