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IMPROVING A BIOGAS PLANT PARAMETERS IN THE CONVERSION CONTEXT OF REPLACING THE CORN SILO WITH AGRI-FOOD WASTE

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Abstract

The large amount of organic waste resulted from the large urban agglomerations is an important source of landfill gas and consequently represents an important factor in the climate changing pollution effect. Although there are consistent efforts to reduce the volume of organic waste or to process it in a way which generate less landfill gas, there it is more work to be done in order to solve this problem. This article presents the work conducted to convert a biogas plant originally designed to use corn silage into a biogas plant which uses agri-food waste. Another important aspect presented in this article is the research on improving the qualitative parameters of biogas and the technical modifications conducted on the initial design to achieve a double quantity of biogas.

Key words: *agri-food waste, biogas, biogas plants.*

INTRODUCTION

Using land for cultivating crops that are meant to be used in biogas plants instead of food is not the best solution. The United Nations (UN) deemed food waste reduction as a global priority and included it in the list of sustainability goals (United Nations. Transforming our world: The 2030 agenda for sustainable development). Following this reality many countries changed their approach regarding the substrates that are going to be used in biogas plants (Galit et al., 2019; Brémond et al., 2021). In the USA the EESI (Environmental and Energy Study Institute) presented a plan (Fact Sheet | Biogas: Converting Waste to Energy) for 13500 biogas plants based on waste to be opened. In Europe EBA, (European Biogas Association) issued strong recommendations (Circular Economy and Waste Management) to the EU Council regarding the need to ensure quick and efficient implementation of the Waste Framework Directive to force separate collection of organic waste streams and its treatment according to the waste hierarchy. Anaerobic Digestion makes the best use of organic materials by producing renewable energy and organic fertilizer while closing the nutrients cycle and reducing greenhouse gas emissions (Dobre et al., 2014; Baredar et al., 2020). However, both in USA and in Europe there are very few examples of biogas plants using only food waste, due to the lack of experience in this field.

To this moment there are implemented thousands of biogas plants around the world however, many of them relays on corn silage, maize silage or manure as feedstock (Sravan et al., 2021).

There is a real challenge in adapting the technology initially implemented for using corn silage in these plants and making them suitable to use agri-food waste as feedstock (Diguta et al., 2007; Ohnmacht et al., 2021). Different substrates with different dimensions present different digestion rates also, the availability of different categories of waste varying from season to season as well as the quantises of agri-food waste randomly depending on social events and/or accidents that appear on food production lines (Liu et al., 2021). All these aspects make almost impossible to establish a certain mix of waste material, with well-established dimensions and controlled

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properties capable to be introduced in the fermenter and to deliver a constant output (Prabhu et al., 2021).

MATERIALS AND METHODS

The configuration of the facility used for test is a classic biogas plant consisting in fermenter tank, post-fermenter tank and digestate storage tank as well as the feeding system. The plant layout is presented in Figure 1.

Figure 1. Initial biogas plant design

The research was conducted over a period of 5 years and encompasses three main methods:
1. Replacing in a controlled manner the corn silage substrate with agri-food waste materials;
2. Analyse both the output of biogas and biological environment in the reaction tanks;
3. Tuning the composition of feedstock and its properties (size and concentration of dry materials) to continuously improve the quantity and quality of the produced biogas;

In order to achieve the established objective, a complex and flexible research methodology was elaborated, starting from the few research data existing (Popescu & Jurcoane, 2015) but keeping an open mind to absorb all the novelty elements that appeared along the way. Thus, the latest study methods, simulations of underlayermixingwereused.Hardware elements such as agitators introducing new products equipped with carbon fiber propellers, crushing installations as well as nutrient inputs to compensate for the nutrients which were missing during the replacement of the underlayers, were installed.

Before the experiments started a thorough study on the market was conducted and the type and quantities of agri-food waste were established as presented in Table 1.

Table 1. Available agri-food waste

Materials	Monthly average [t]	Annual average [t]
Fruits and vegetables	488796.00	5865555.00
Meat and meat products	21760.00	261115.00
Bakery and pastry	15722.00	188659.00
Dairy and eggs	25432.00	305180.00

Experiments conducted

The experiments performed for reaching this goal were extensive, involving detailed analysis of the main parameters influencing the fermentation process pH, FOS (volatile organic acids), TAC (alkaline buffer capacity), FOS/TAC ratio (FOS/TAC measure the risk of acidification of a biogas plant) and CH_4 content in the biogas obtained and the quality of the digestate obtained. Furthermore, in order to avoid the impact on the biogas production, the underlayers used were also analysed, constantly controlling the content of carbohydrates, starches, proteins, fatty acids, pectin, cellulose, hemicellulose, etc., the percentage of organic matter contained in the dry matter, the micronutrients contained, for the fed underlayers.

Table 2. The planning/implementation of substrate changing

Year	Agricultural biomass (%)		Agri-food waste (%)	
	Planned	Realised	Planned	Realised
2015	80.00	81.67	20.00	18.33
2016	50.00	48.72	50.00	51.28
2017	30.00	28.48	70.00	71.52
2018	10.00	11.94	90.00	88.06
2019	<5	2.46	95.00	97.54
2020	Maintain stability of the process with less than 5% biomass from agriculture			

The planning of experiments (replacing the agricultural biomass with agri-food waste was established based on consultation with some other specialists in this area as presented in the Table 2.

There it was well establish to implement a continuously monitoring regime of the main parameters in such a way to be ready to apply the required correction if the fermentation

process is presenting dysfunctions. Also, it was established to consider as main indicator of the entire process the daily readings of quality and quantity of the produced biogas. If any perturbations occurred this was a trigger for additional sampling and analysing of material from fermenter and post fermenter.
In parallel with the gradual change in the ratio between underlayers, a study was performed on other process elements such as shredding the underlayer, mixing it to homogenize heat and nutrients throughout the volume of the fermenter to optimize biogas production.

RESULTS AND DISCUSSIONS

Although during the entire period were collected monthly samples of materials from fermenter, post fermenter and biogas which were analysed, in this study are presented only the results which are indicating significant changes in the fermentation process.
In 2015 the monthly analysed samples from fermenter reports for pH, FOS, TAC, and FOS/TAC are presented in Table 3.

Table 3. The results of analysis conducted in 2015

2015	pH	FOS	TAC	FOS/TAC
	[-log.c H+]	[mgHAcäq/l]	[mgCaCO₃/l]	[-]
Jan	7.64	2.79	10.31	0.27
Feb	7.57	3.00	11.67	0.26
Mar	7.55	2.89	11.47	0.25
Apr	7.55	2.91	11.55	0.25
May	7.54	3.30	11.41	0.29
Jun	7.43	3.06	12.02	0.25
Jul	7.57	3.10	12.08	0.26
Aug	7.61	3.93	13.07	0.30
Sept	7.72	3.70	15.39	0.24
Oct	7.85	4.37	17.30	0.25
Nov	8.04	4.21	17.98	0.23
Dec	8.11	6.63	20.02	0.33

It is significant to observe that although both FOS and TAC are slowly increasing, the report FOS/TAC is maintained constant which prove that the fermentation process is stable and the biology into the fermenter is slowly adapting to the substrate changing.

Thus in 2015, when the experiments started, the components of biogas were quite stable as presented in the Figure 2, although there it is a slow increase of the amount of CH_4 from 51.1% to 54.1%.

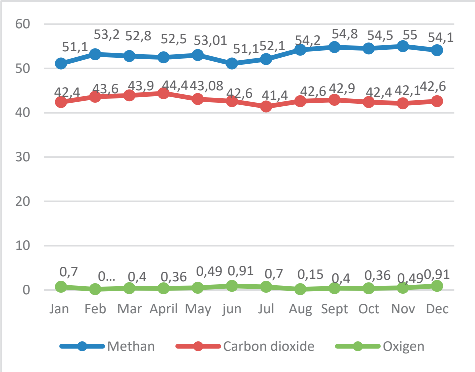

Figure 2. Biogas components analysis in 2015

Although apparently the process was varying smooth and there was an improvement in the biogas quality it has to be mentioned that in this first year 20% of agri-waste materials consisted of fruits and vegetables and this could be an explanation of process stability over the substrate changing.
In 2016, the changing was much significant since the target was to replace up to 40% of corn silage and in addition to the fruits and vegetables, were added meat, fats, bakery and pastry as well as dairy products and mixed together.
As it could be observed in the Table 4 the FOS and TAC values were growing higher which provided the information that the fermenter was over-feed.
Gradually the quantity of organic material feed to fermenter was downsized in order to lower the values of FOS and TAC. The process of correlating the amount of material fed to the fermenter with the FOS TAC variation was difficult and improvements were obtained only at the end of 2016.

Table 4. The results of analysis conducted in 2016

2016	pH	FOS	TAC	FOS/TAC
	[-log.c H+]	[mgHAcäq/l]	[mgCaCO₃/l]	[-]
Jan	8.11	7.308	20.18	0.36
Feb	8	9.67	24.597	0.39
Mar	8	8.129	25.235	0.32
Apr	8.2	11.272	28.601	0.39
May	8.1	11.494	25.309	0.45
Jun	8.2	13.551	22.101	0.61
Jul	8.1	16.227	23.732	0.68
Aug	7.9	14.936	26.572	0.56
Sept	8	11.049	23.239	0.48
Oct	8.1	11.494	25.309	0.45
Nov	8.04	4.213	17.984	0.23
Dec	8.11	6.629	20.024	0.33

Although the process control was difficult the output of biogas was good, the increase of CH_4 into the biogas produced growing with over 1% as presented in Figure 3.

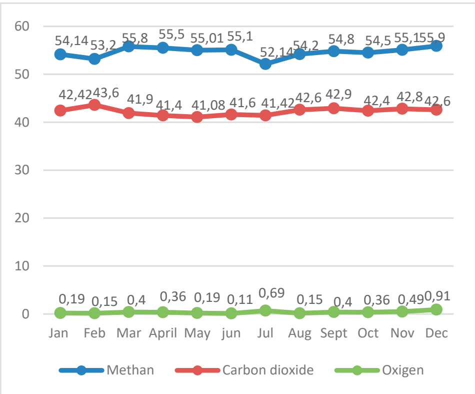

Figure 3. Biogas components analysis in 2016

Although the diversity of materials introduced as substrate was increasing, based on the acquired experience in 2016 the amount of agri-food waste feed to the fermenter was much better controlled. The quality of the substrate introduced into the fermenter was better correlated with the quantity delivered and thus the previous variations of substrate fermentation were reduced significantly.

In 2017 the changes were controlled better and the amount of agri-food waste material feed was raised up to 71.2% and further diversified adding gelatine, Omega 3 pills, chocolate, and potatoes chips. The increased value of NaCl in potatoes chips produced some small variations into the FOS value, however, due to the continuous monitoring process it was possible to add some other materials which compensate this inconvenient (Table 5).

Table 5. The results of analysis conducted in 2017

2017	pH	FOS	TAC	FOS/TAC
	[-log.c H+]	[mgHAcäq/l]	[mgCaCO₃/l]	[-]
Jan	8.00	11.05	23.24	0.48
Feb	8.20	6.47	27.70	0.23
Mar	8.20	6.48	27.10	0.24
Apr	8.30	10.17	29.53	0.34
May	8.20	10.60	27.75	0.38
Jun	8.00	9.55	28.81	0.33
Jul	8.20	10.60	27.75	0.38
Aug	8.00	9.55	28.81	0.33
Sept	8.20	10.80	29.14	0.37
Oct	8.00	12.36	28.79	0.43
Nov	8.20	10.60	27.75	0.38
Dec	8.20	6.48	27.10	0.24

The quantity of CH_4 in the produced biogas was increasing from 55.9% in 2016 up to 59.1% in 2017 as presented in Figure 4.

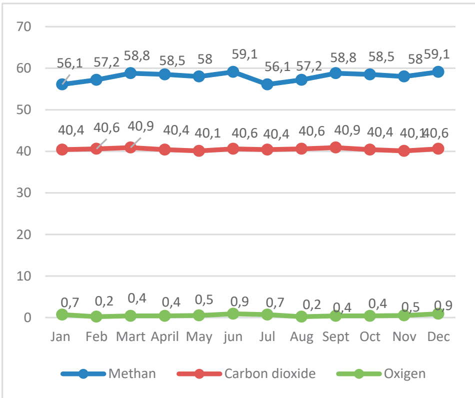

Figure 4. Biogas components analysis in 2017

This improvement of biogas quality had a good impact on the CHP functioning, the gain obtained being significant. Another advantage observed was related to the CO_2 content in the produced biogas. The CO_2 content was decreasing from 42% in 2015 to 40% in 2017.

In 2018 the goal was very ambitious, to decrease the content of corn silage down to 10%. In the previous years the corn silage was used as a fermenting reaction "regulator" being used when it was necessary to compensate variations of fermenting process and the 30% material used was enough to control the system. With only 10 % corn silage available it was much more difficult to regulate the process taking also in consideration that some quantities of sludge were added to the fermenter. The variation of quantities of agri-food waste was now significant as presented in Figure 5.

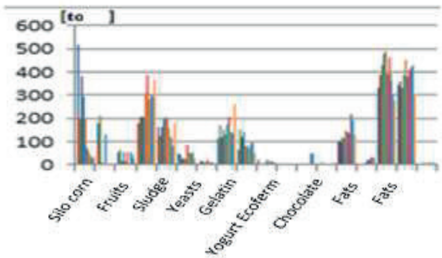

Figure 5. Variation of quantities of agri-food waste

Although the challenge was higher the team was able to control the system and as presented in Table 6, the obtained results were within the margins of required operational values. Due to the need to reduce operational costs there it was taken the decision to conduct sampling and testing at two months.

Table 6. The results of analysis conducted in 2018

2018	pH	FOS	TAC	FOS/TAC
	[-log.c H+]	[mgHAcäq/l]	[mgCaCO₃/l]	[-]
Feb	8.2	6.482	27.096	0.24
Apr	8.3	10.168	29.528	0.34
Jun	8.2	10.602	27.746	0.38
Aug	8	9.55	28.813	0.33
Oct	8.2	10.804	29.143	0.37
Dec	8	12.362	28.787	0.43

The biogas quality and quantity were good as presented in the Figure 6.

During 2019, only adjustments were made to the system. Small amounts of corn silage have been intentionally withdrawn/introduced to see if it is possible for biology to function without corn silage. It is noteworthy that during this year a complete replacement of corn silage was achieved.

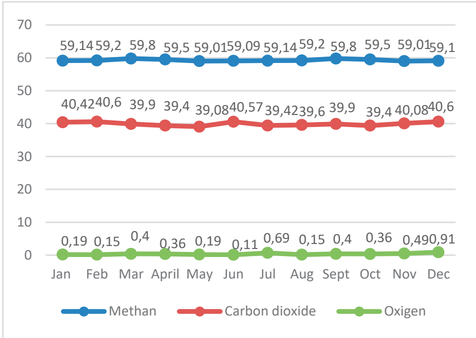

Figure 6. Biogas components analysis in 2018

The analysis proved that the system is functioning well as presented in the Table 7.

Table 7. The results of analysis conducted in 2019

2019	pH	FOS	TAC	FOS/TAC
	[-log.c H+]	[mgHAcäq/l]	[mgCaCO₃/l]	[-]
Mar	8.3	6.579	28.561	0.19
June	8.4	6.245	26.894	0.19
Sept	8.4	6.625	28.857	0.19
Dec	8.4	6.650	28.055	0.19
Feb 2020	8.4	6.822	28.123	0.19

The biogas produced contained around 59% CH_4 continuously and the amount produced was constant at 500 m^3/hour.

Modifications conducted on biogas plant

Based on the experience gained during the 5 years of experiments, there were conducted several modifications to the plant in order to improve and adapt its capabilities to process agri-food waste:

One of the first modifications was to introduce a liquid waste tank where lower quality substrates are mixed with higher quality substrates as presented in Figure 7. Another advantage of this tank is that the process of hydrolyzation would start in advance and when introduced in the fermenters the substrate will be digested by the existing biological media faster reducing thus the time of mineralization and increasing the output of biogas.

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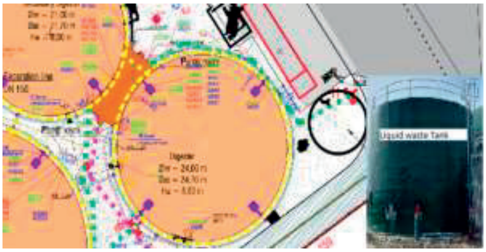

Figure 7. Liquid waste tank

The second step of modification was much bigger involving the transformation of the post fermenter into a fermenter and of the digestate storage tank in post fermenter. The transformation of the post fermenter into a fermenter was quite simple requiring to establish a separate feeding line for the substrate. The modification of the digestate storage tank was quite complex requiring installation of two additional mixers, separate feeding lines from fermenters, insulation of the tank on the outside with styrodur and steel plates as well as the installation of a tank heating system (Figure 8) capable to maintain the temperature of the digestate at 40^0C.

Figure 8. Heating system installed into the post fermenter

Due to the need of better processing the agri-food material a significant improvement was conducted at the solid feeding system. There a grinder provided with a stone removal system was installed to avoid the destruction of the pumps by the stones mixed with potatoes.
The last major improvement was the results of periodic analysis of material inside fermenter in 2018 presented in Figure 9. While the corn or any other technical crop silage does not require hygienization, the use of agri-waste materials requires by law to install a hygienization station (Figure 10) capable to process the estimate of 40-60 tons of digestate per day.

Figure 9. Grinding system installed at the exit of solids feeding system

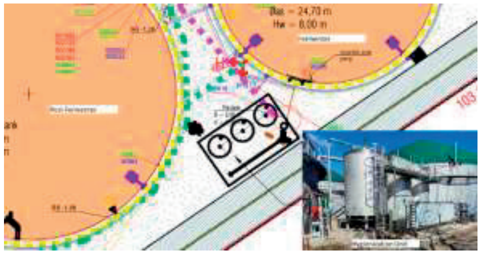

Figure 10. Digestate hygienization station

CONCLUSIONS

The conversion of BIO 2 Filipestii de Padure biogas plant was a process that required quite a long period of time and significant technological modifications; however, the result was successful and lead to a major improvement in its capacity.
Through the introduction of additional grinders, the size of input materials was reduced from 7 cm to less than 3 cm and consequently the digestion time was reduced in a significant manner. Thus, the digestate retention time for complete mineralization was reduced to less than 3 months. This fact provided the opportunity of changing the post fermenter into a second fermenter and consequently of the digestate storage tank into a post fermenter.
These changes increased the capacity of biomass processing and consequently increased biogas production from 500 m^3 to 1000m^3. The additional biogas was used in a second CHP providing the necessary amount of thermal power for the digestate hygienization station and the electrical power for internal use.

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Although the conversion required a significant investment, the expected economic return is quite high considering that instead of buying the plants silage the factory will receive the gate fee for the processed waste.

The most significant result is however, the environmental impact of this conversion. Through the bio digestion of agri-food waste there it will be avoided the release of a large quantity of landfill gas with a great impact on greenhouse effect.

There it could be concluded that the work conducted in BIO1 Filipestii de Padure was a pioneering work for Romania and the experience acquired during this research could be used further into the development of new such facilities both in Romania and around the world.

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