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Valorization Capacity of Slaughterhouse Waste in Biogas by a Tarpaulin Digester in Dakar, Senegal

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Abstract: The recycling of waste into biogas inevitably occurs in hermetically sealed enclosures called bio-digester. Our study focuses on the recovery capacity of slaughterhouse waste by a tarpaulin bio-digester installed at the Dakar abattoir with a capacity of 4000m^3 including a digester of 2500m^3 and a gas meter of 1500m^3. During our work, we have tried to understand the primordial factor favoring the obtaining of biogas in quantity. The studied system being in industrial size, the water retention time was programmed over 40 days according to the data of the company and according to the characteristics of the substrate, the pH was observed, and the temperature set on a mesophilic range. We have noticed that the considerable increase in wastewater (blood + wash water) for a minimal amount of rumen content is favorable to a better biogas yield. It shows that the content of our biogas consists mainly of CH_4, CO_2, O_2, and H_2S measured using a Severin Multitec 540 Device for the analysis of biogas in the field. (Quality feature on 1m3 of biogas produced). The biogas is then purified and used to power a cogeneration engine, generating electricity and heat. The implementation of this digester has made it possible to solve an environmental problem related to the waste and the valorization of the latter as essential energy for the study system.

Keywords: Slaughterhouse Waste, Digester, Water Retention Time, Biogas, Cogeneration, Environmental

1. Introduction

In the current global contexte, the management and the valorisation of organique waste, in particular biomass constitutes a considerable economic, environmental and energetic stake, the use of this last one is at the same time a necessity and an economic opportunity opening new ways for the sustainable development [1-2]. With ever greater and more diversified consumption around the world, the production of waste continues to increase in quantity and quality, thus generating enormous risks for the environment and, consequently, for the health of the population [3-4]. Result of the mechanization or anaerobic digestion of fermentable waste in hermetically sealed enclosures called digester, the purified biogas [5] is used as green energy and is presented as an alternative source of energy to replace the fossil fuel [6-9]. It is an opportunity for diversification of energy resources and sustainable management of the environment in rural areas.

Zemene Worku and Seyoum Leta (2017) are shown in their article on Anaerobic Digestion of Slaughterhouse Wastewater for Methane Recovery and Treatability [10] that meat production is increasing to fulfil the protein needs of the ever increasing world population which in turn has environmental pollution problems attached [11] due to the large quantities of wastewater generated from the slaughtering, processing and preserving activities required for meat production in municipal slaughterhouses. It is estimated that for every cow and pig processed, 700 and 330 liters of wastewater are generated, respectively, with an increase of 25% if further processing is carried out to produce edible products [12]. This wastewater is a complex mixture of compounds containing mainly organic materials with high concentration, a measured Chemical Oxygen Demand (COD) loading as high as 4,000-10,000 mg/l is typical for such wastewater [13-15]. It also contains high concentration of suspended solids, colloidal materials such as fats, proteins and cellulose [15]. Hence, the major environmental problem associated with this slaughterhouse wastewater is the large amount of organic matter or suspended solids and liquid waste as well as its odor generation released to the environment [16]. Effluent from slaughterhouses has also been recognized to contaminate both surface and groundwater due to the fact that blood, fat, manure, urine and meat tissues are lost to the wastewater streams during slaughter processing [17]. Blood, one of the major dissolved pollutants in slaughterhouse wastewater, has the highest COD of any effluent from abattoir operations [18]. If the blood from a single cattle carcass is allowed to discharge directly into a sewer line, the effluent load would be equivalent to the total sewage produced by 50 people on average day [19].

Thus the recovery of waste in general and those of the abattoir in particular, contributes because of its high methane content to the reduction of greenhouse gas emissions. The energy produced from biogas is a renewable energy because methane is produced from organic waste. The Senegalese government has set itself the goal of developing and disseminating bio-digesters as an alternative and modern renewable energy solution in rural areas. In response to this objective, the Dakar abattoir uses the waste it produces to transform it into electrical energy that minimizes the cost of energy and thus enhances the waste of the slaughterhouse. To make this process possible, the Dakar slaughterhouse, in collaboration with ThecoGaz Senegal, has installed a bio-digester with a capacity of 4000m3, for the production of heat and electricity by means of a Co generator [20]. Our objective is to study the physicochemical characteristics and the capacity of this bio-digester to produce energy by the valorization of slaughterhouse waste.

2. Materials and Method

To achieve high levels of biogas production, close contact between the bacteria and the substrate is required, which is generally achieved with an effective mixture in the digestion vessel. Good agitation avoids the production of crusts and the settling of dense particles, which breaks the supernatant layer and thus facilitates the escape of the biogas.

Substratum

Throughout our work the substrate was composed of: Contents cattle belly + Contents sheep body & goats + Manure cattle + Manure sheep and goats + Waste water + Blood slaughtered animals + (sometimes) Other external waste.

2.1. Device - Materials

It is a 45m^3 capacity pre-mix well with 13 kW submersible mixer-grinder pumps installed in the well, a state-of-the-art safety system and a booth. control (pressure measurement, safety valve in case of under / overpressure), a CHP group with a power of 100 kW. A safety valve is placed on the dyke of the digester. It can handle overpressure or under pressure. It is hydraulically operated, depending on the pressure or lack of pressure, the liquid releases or draws biogas to manage the tension in the tank. In addition to the safety valve, a flare makes it possible to burn excess biogas in case of intervention in the digester or the system. The consumption of CHP is 2m^3 / h and the biogas used must contain at least 45% methane (CH_4); Hydrogen sulfide (H_2S) must be less than 200 ppm and no trace of water. To do this, the biogas is purified by passing through the desulfurizer to have the bio-methane required to operate a gas engine.

2.2. Overview of the Bio-Digester

Figure 1. *Photo Digester pit.*

The bio-digester is made in a tarpaulin designed for anaerobic digestion with a capacity of 4000 m^3 gross for more or less 1000m^3 of gas produced. The digester is inserted into a pit whose dimensions are 36x36m and the depth of 2.75m; The digester is heated by plastic pipes specially designed for this purpose and placed at the bottom of the pit as shown in Figures 2 and 3. This heat exchanger system allows to maintain the temperature in the optimal conditions of production (between 25 and 40°C), [3,20] temperature required in anaerobic environment for the development of mesophilic bacteria [21-24]. Equipped with a temperature probe installed in the bio-digester, the measurement of the latter is done regularly to maintain the average in a mesophilic interval [25-27]. The generated biogas is stored in the upper part of the tank as described in photo 2 below and the storage capacity of the membrane is 1500 m3 of gas. The digester is equipped with several lines for gas evacuation, substrate filling, digestate disposal, desulfurization, mixer, several small pipes for cables and a safety device in case of underwater / or overpressure to suck air in the case of a maximum filling of the tank or blowing air in the opposite case.

Figure 2. *Photo SOGAS Dakar Tarpaulin Digester.*

The tarpaulin weighs 1100 g per m^2 and is PVC-P, with good UV resistance, elongation at break of 18/25%, tear resistance of 400 N and can withstand temperatures between -30 and + 80°C [9].

2.3. Experimental Description

The introduction of the substrate in our case is done beforehand by a mixture of the various constituents of the substrate in the mixing well. Using the submersible mixer-mixer pump the mixture is then sent into the digester by the lower part and the digestate is removed by the middle portion of the digester, the gas being withdrawn by the tarpaulin directly while respecting certain number of instructions specific to the company. The mixture stays in the digester for a fixed period of time and sampling is carried out each specific period to know the qualitative constitution of the biogas. The aim being to respect a percentage suitable for use in a cogeneration engine for electric production and heat.

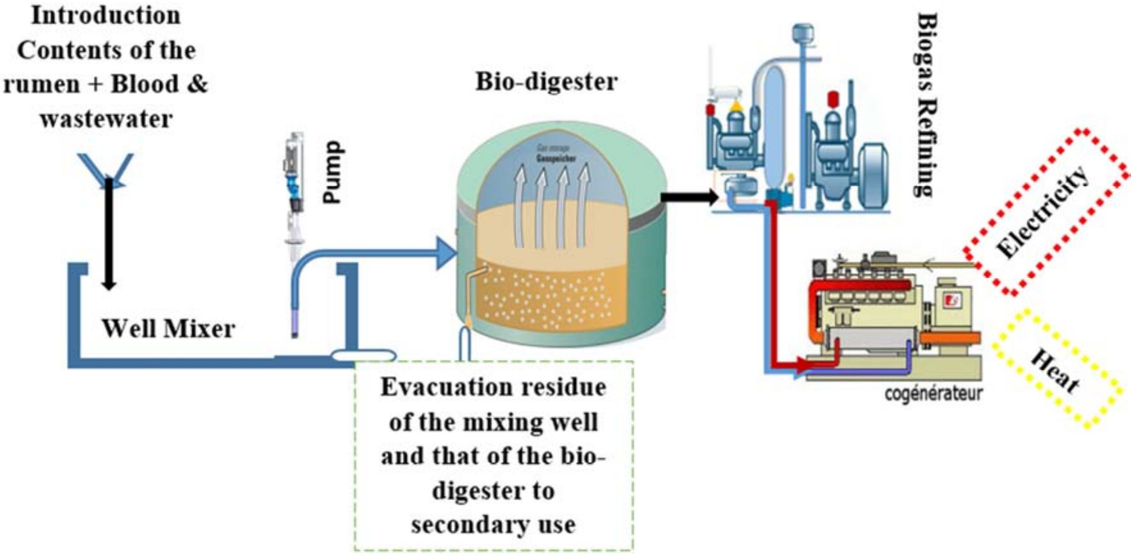

Figure 3. *Biogas production system.*

Table 1. *General characteristic of the bio-digester.*

physical characteristic / Type of digester		industrial	
Capacity	Gasometer	1500m3	Total of 4000m^3 off mixing well
	Digester	2500m3	
	mixing well	45m3	
digestion procedure		Continuous	
		Different quantity each day	
Nature of the substrate		Content of rumen	
		Blood	
		Used water	
		Manure	
water retention time		40 days	
temperature		Mesophilic range [25 to 40°C]	
pH		Varies from 7 to 8.79	

The analytical monitoring and the experiments being carried out in field conditions on real biogas; we are subjected to several hazards including that of the ground, the climate, changes in the volume of the ratio. Mainly, the composition of biogas is not always the same from one day to another or even throughout the day and from one month to another or even during the year. This induces higher uncertainties than during rigorous laboratory manipulations. These experimental follow-ups nevertheless remain closer to the industrial problem and to the reality of our "terrain".

3. Result and Discussion

By monitoring the physical parameters that we have performed on the bio-digester Thecogaz, we noticed that regardless of the amount of substrate in variable proportion, it does not affect the quality of the biogas by cons when we change the quality of the substrate a variation of the characteristics of the biogas is obtained.

3.1. Control and Monitoring of Physicochemical Parameters

Several parameters make it possible to control the processes of anaerobic digestion [28-29] KALIA et al. (1992) proved that the digestion efficiency could be increased or slowed according to the nature of the waste [30]. In our case study, we propose to study by the physical characteristics of the digester the parameters that influence on the quality of the biogas obtained.

3.1.1. Temperature Control

The monitoring and control of the temperature is done thanks to the connection system of the temperature probe integrated in the digester to maintain and measured the appropriate temperature for a better production. (Mesophilic beach). Reading, measuring and changing the temperature is done from the control cabinet and optimizing the control parameters.

During our work we recorded several temperatures according to the different months during the two years. The average of these temperatures was in the mesophilic range between 27 and 37 ± 2°C.

Table 2. *Biogas production versus mean temperature on the mesophilic range.*

Mean temperature Production	Year	quantity of biogas
33,9°C	2014	244620m^3
36.8°C	2015	275280m^3

3.1.2. pH Observation

Assuming that pH is one of the best indicators of a digester malfunction and the poor production of biogas due to the presence of inhibitors, the global measurement of hydrogen ions using a pH meter to better understand and adjust the latter. Anaerobic digestion is optimal in the vicinity of neutrality (7.2 ± 0.5) [31]. The pH disturbances can come as much from organic matter introduced into the bio-digester as from a temperature change favoring a group of microorganisms producing acids or bases. Thus, there are several data including: Zinder et al between 6.5 and 7.3 [32]. For Ward et al. in 2008 between 5.5 and 6.5 [33]. Habouzit, in 2010 between 6 and 8 [34]. This is explained by the fact that each bioreactor is unique depending on the type of bio-methanization (base, medium or high temperature), inputs and communities of microorganisms that populate it. However, it is estimated that the pH should be between 5.5 and 8.5 and that the optimum is between 7.0 and 7.2. The biggest problem in the bio-methanation process is the accumulation of acids leading to a drop in pH. [35]. In our case study of the ThecoGaz system we were able to measure an average pH between 7 and 8.79. During the biogas production process the pH parameter was not adjusted for the simple reason that during the pilot phase of the system, we wanted to work under the sole control of the steps of the anaerobic digestion process. However, we have noticed in some periods the almost total absence of biogas production and in some cases a surplus of biogas production up to the flare of a given amount in order to respect the dedicated capacity in the gas meter. For non-production or reduction of biogas production, this can be explained by the presence in the substrate of certain types of microorganism favoring the inhibition of organic matter. These inhibitors are contained directly in the contents of the animals' stomachs and which had probably absorbed them in their feeds. The chemical analysis has made it possible to justify the presence of certain inhibiting elements in the characteristics of the substrate.

3.1.3. Parameter of the Water Residence Time

For the residence time in our case, the introduction of the substrate was introduced according to a method specific to Thecogaz: during the first 40 days, [36] the substrate was introduced every day at different proportions to have a maximum of 2500m3 of substrate in the digester. At the end of the 40th day a quantity of substrate is introduced while drawing 80% of the existing quantity.

3.1.4. Analysis of the Major Gas Content

A portable, multi-gas meter has been used for its simplicity and reliability. The compounds detected are: CH_4, CO_2, O_2 and H2S. The device operates in temperature ranges from - 10°C to + 40°C. It allows to know in real time the quality of biogas analyzed in the field. Then the biogas produced must be purified [37].

Table 3. *Characteristic of the biogas content obtained from slaughterhouse waste.*

major gas	Variation of the average grade	
	raw biogas	refined biogas
CH4	54 to 74 %	56 to 78%
CO2	16 to 23%	16 to20%
O2	0.2 to 5 %	0,01 to 2,6%
H2S	0,11 to 360ppm	≤2ppm
else matters trace Presence		
H2O	<1%	
N2	<1%	
NH3	<1%	
H2	<1%	
Other	<1%	

These results are highly acceptable and allow to produce electricity and heat through a Co-generator. The biogas treatment aims to satisfy two processes for a better purification. The first is to eliminate toxic and corrosive compounds, and the second is to increase the proportions of methane to improve the energy properties of the gas mixture. The purification of our biogas follows the following reactions: [38].

$$Fe_2O_3 + 3H_2S \rightarrow Fe_2S_3 + 3H_2O;$$

$$Fe_3O_4 + 4H_2S \rightarrow FeS + Fe_2S_3 + 4H_2O;$$

$$FeO + H_2S \rightarrow FeS + H_2O$$

3.1.5. Analysis of the Influence of the Type of Load on the Production of Biogas

The two histograms of 2014 and 2015 clearly show that the amount of waste water has a direct influence on the amount of biogas produced. The more liquid the substrate, the better the production of biogas. For substrates almost identical except for the presence of manure used during (4) four months in the year 2014 the results on the characteristics of the biogas remain the same in a composition of CH_4, CO_2, O_2, and H_2S.

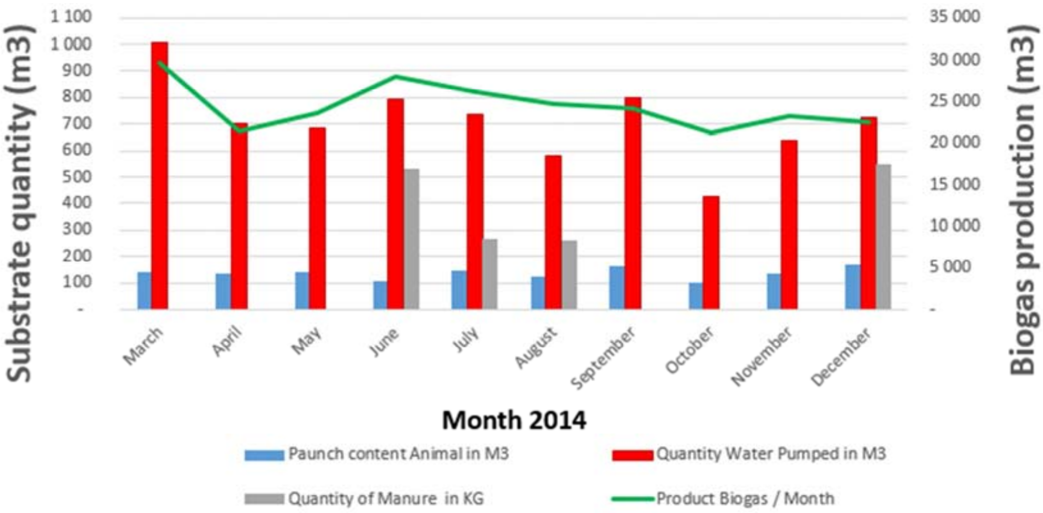

Figure 4. *Influence of wastewater on biogas production in 2014.*

In 2014 we had biogas from March, following an average temperature of 28.9°C during this month. The influence of this production is due to the load consisting of 140 m3 of rumen content mixed with 1005 m3 of waste water (blood + waste washing water). Another aspect is the addition of manure during the months of June, July, August and December. This has also increased the efficiency of the biogas. However we also find that with the addition of manure the temperature was adjusted to more than 35°C ± 2 but we had a good performance.

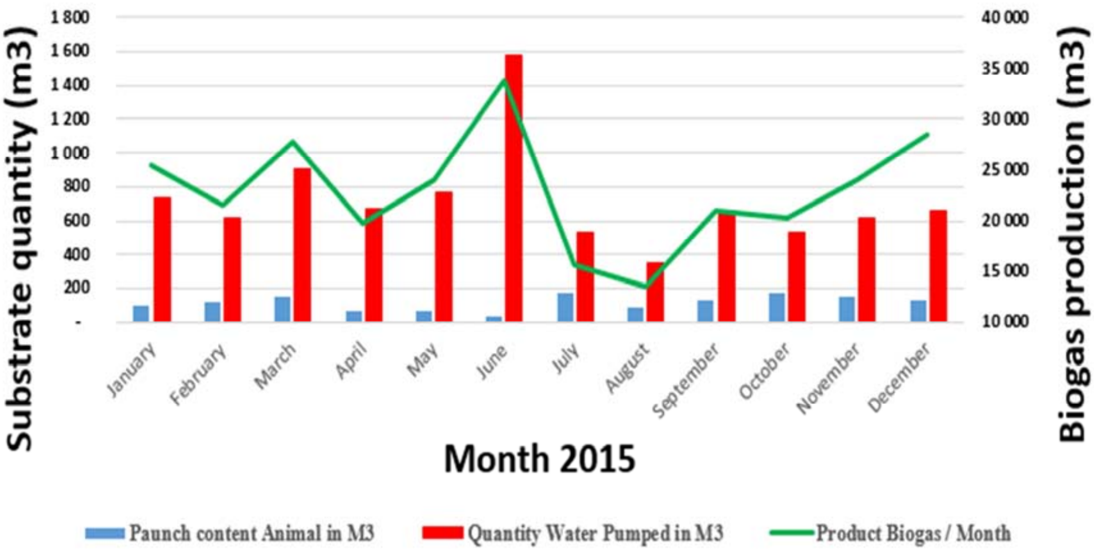

Figure 5. *Influence of waste water on biogas production in 2015.*

As for the 2015 production, the amount of biogas produced is much higher than in 2014, with a higher average temperature than the previous year. For the higher peak observed in June this is also due to the presence of a very large amount of water (blood + wash water) mixed with a small amount of rumen content and an average temperature of 38.90°C.

The methanogenic potential of a mixture of substrates may be different from the sum of the methanogenic potentials of the constituent substrates of the mixture [39]. In some cases, the methanogenic potential of a mixture of substrates is greater than the sum of the methanogenic potentials of the constituent substrates, which reflects a synergy between the substrates of the mixture whereas, in other cases, an antagonism is observed. Substrate mixing conditions can significantly impact the performance of the digester for biogas production. As in our case, the water charge consisting of blood plus washing water of the carcasses and remnants of waste such as fats and meat possessing very high methanogenic potential added to the rumen content mixed with the blood [40] has a considerable impact on biogas production [41]. For all other peaks we found that the amount of waste water pumped was much higher than that of rumen contents.

3.1.6. Analysis of Energy Production from Biogas Produced

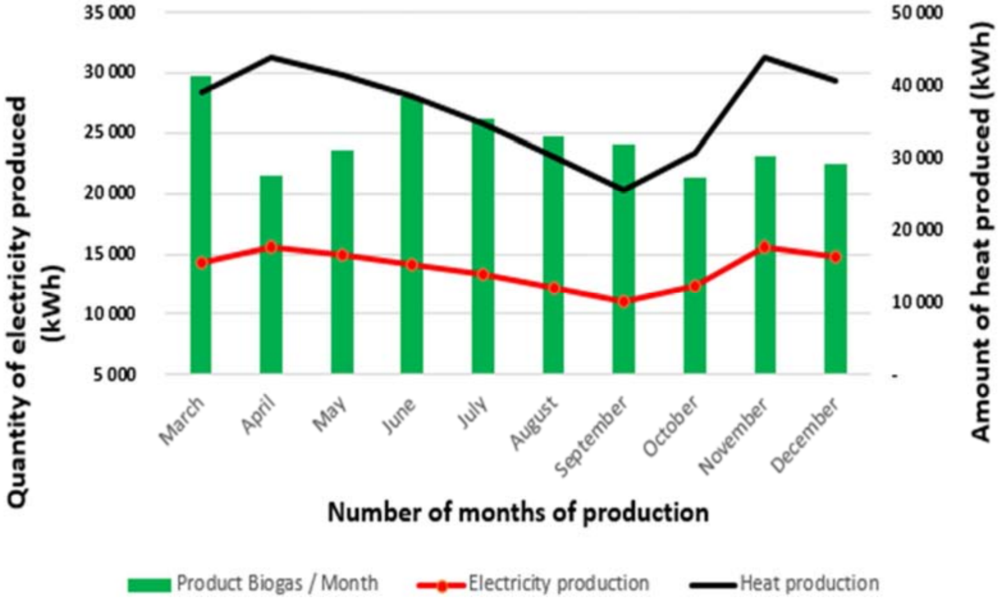

Figure 6. *Energy production (heat and electricity) according to biogas in 2014.*

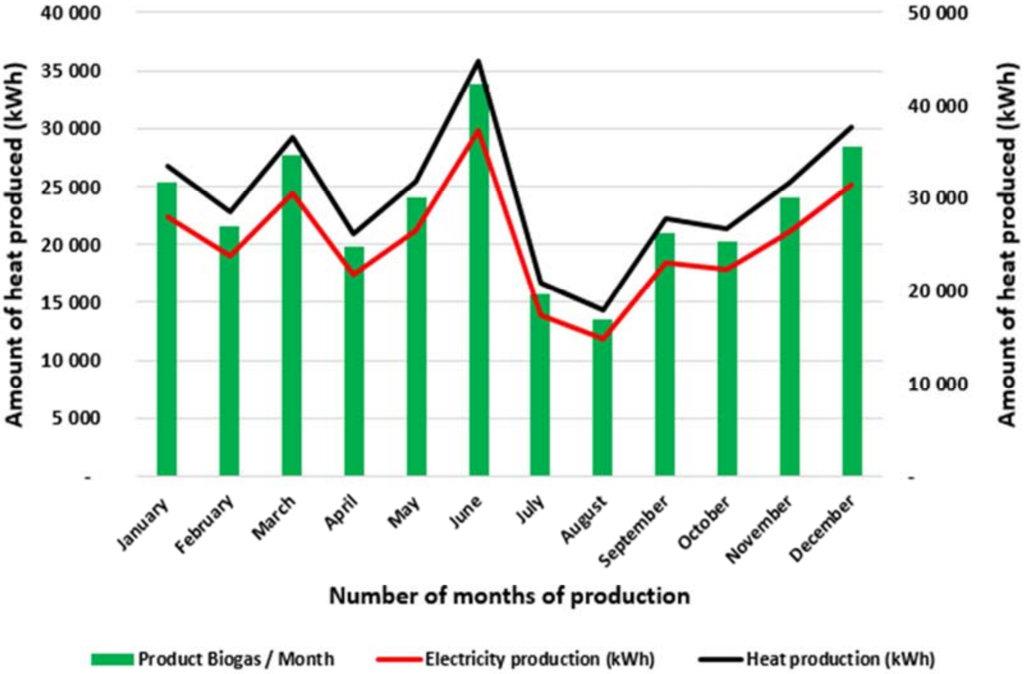

Figure 7. *Energy production (heat and electricity) according to biogas in 2015.*

The amount of biogas (green histogram) produced could run the generator to produce electricity (curves in red) and heat (curves in black). However, the heat output was higher than that of the generator. Electricity. More heat is produced each year than electricity. The heat produced is used to maintain the bio-digester in a mesophilic temperature range and the electricity is mainly channeled in the cold rooms and some low-voltage connections in the offices and the lighting of the slaughterhouse.

3.2. Improved Biogas Yield Over Two Years (2014-2015)

Finding a good return from existing data is a good example of optimization. In order to be able to make a good optimization according to the increasing yield, it is often necessary to smooth "positive raw data" to minimize imperfections and remove unwanted ones. It will be a question of determining a set of samples taken in increasing ways in our case in order to obtain applicable data for a better performance.

In order to adjust a larger set of sampling measures it is important to have a sufficient number of samples depending on the availability of the data and as needed. Thus we propose to choose the best biogas production data depending on the substrate and the operating parameters. After selection we have data that grow according to the graph below.

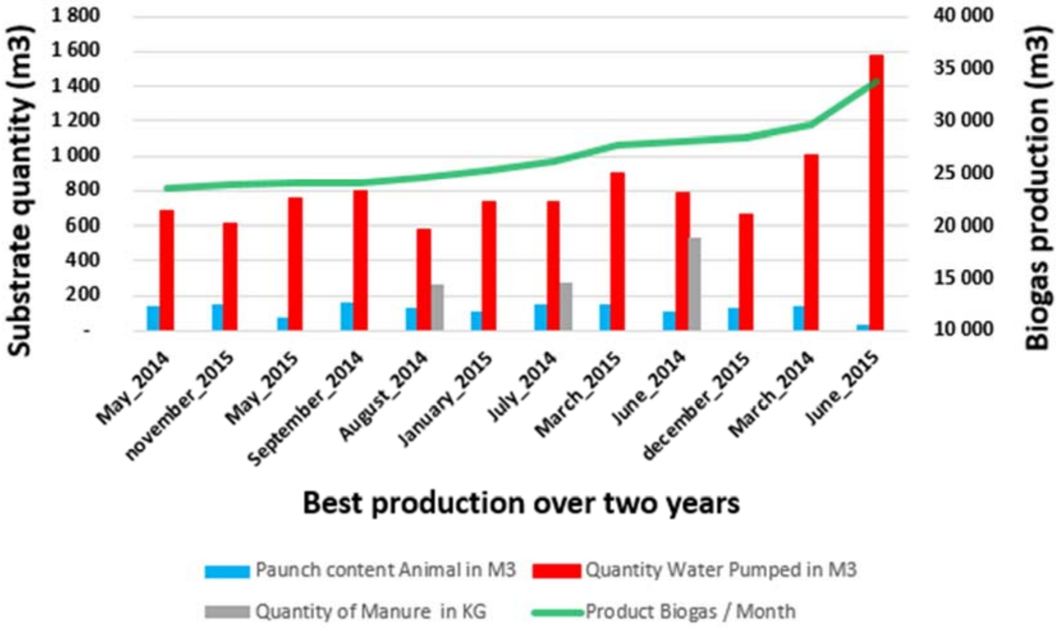

Figure 8. *Improved biogas yield over two years (2014-2015).*

The 12 growing samples we have taken over a 24-month period, representing all of our production data, show the best biogas yields for the company. These data give the range of production between 23580m^3 and 33870m^3 of biogas and it is thought that if it is respected according to already established parameters that is to say the residence time, the temperature, the pH and the types as well as the amount of substrate, the production could satisfy a lot of need. With this, the amount of energy production will be in the range of 16580 to 29806 kWh of electricity and 24870 to 31759kwh of heat. The average annual production in terms of energy from biogas could probably have increased considerably as well.

However, depending on the size of the monthly allowances, the need or the demand for the consumer products, obtaining the quantity could change. Nevertheless for the best biogas results, this interval gives the best growing approach.

4. Conclusion

Anaerobic digestion is one of the major players in sustainable development and the circular economy in the concept of "waste to energy". Given the great diversity of organic waste, its development requires the optimization of co-digestion. Hence the need to develop simple tools to characterize substrates and to predict the performance of digesters to optimize their operation. The main objective of this article was to highlight the physical characteristics of the bio-digester of Thecogaz and its ability to recover slaughterhouse waste in energy production on an industrial scale. Slaughterhouse wastewaters, with the major characteristics of such high organic strength, sufficient organic biological nutrients, adequate alkalinity, relatively high temperature (20 to 30°C) and free of toxic material, are well suited to anaerobic treatment and the efficiency in reducing the BOD5 ranged between 60 and 90% and from different research report point of view, it can be concluded that anaerobic digestion is a high-rate reactor which represents an attractive alternative for wastewater treatment at the slaughterhouse plant.

At the end of this work, it has been shown that the type of installation and the characteristics of the feedstock have a changeable effect on the production of biogas. The characteristics of our biogas are acceptable and could have made the generator run. The yield studied is a function of the higher quantity of water pumped for mixing and feeding into the bio-digester. The pilot project lived up to expectations and more than that allowed having an energy surplus.

The purification of our gas has followed the standard norms for refining and the use of refined biogas has little or no effect in terms of the release into the environment of elements contributing to the gas effect.

The outlook for this study is to increase the biogas yield for two reasons: the first is to produce more biogas in terms of quality and quantity to meet more than 50% of the energy needs of the slaughterhouse. More than 45% of the daily electricity consumption from the national grid and the second alternative is to make a simple mathematical modeling to be able to reproduce the project for another purpose.

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