Artisanal biogas generation of domestic organic waste using waste cooking oil as co-substrate

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Abstract– The objective of this study was to measure the methane generation potential of the combination of domestic solid organic waste and waste cooking oil, through the construction of artisanal biodigesters and an experimentation methodology developed for the project by the author. Both samples of solid and liquid wastes were obtained from previous quantification and characterization studies. Five different dosages were administered to each biodigester going from 0% to 8% of waste cooking oil. Sample 5 was the one with the highest generation (50.48 mg), followed by samples 1 (41.80 mg) and 4 (34.80 mg). The lowest value was presented by sample 2 with only 27,83 mg of methane generation. This research shows that the generation of methane in homes in the city of Guayaquil is feasible.

Keywords—domestic organic waste, waste cooking oil, biogas

I. INTRODUCTION

Since the oil boom in 1971, Ecuador identifies three historical moments in the accumulation of solid waste in the country. The first under the discourse of "throwing the garbage out the window," since there was no greater concern or interest from the government at municipal or national level, it was customary to throw the waste in the public space in general. With the oil boom, and the growing accumulation of waste that was generated, the following speech was taken "throw the garbage in its place," giving birth to regulated open-air dumps, It was not until the year 1990, when the municipalities began to incorporate urban sanitation competencies into their agendas. When these systems began to collapse, for the years 1994 and 1997 in Guayaquil and Quito, the two principal cities of the country, respectively, and later in the smaller cantons, it was then a third speech "throw the garbage in each place" was reached. In this way, sanitary landfills arrived and waste classification was considered as a solution to the problems faced, which also led to the commodification of waste, privatizing and outsourcing these services and eliminating the sectors informal recyclers [1].

According to the information generated by the Ministry of the Environment, Water and Ecological Transition (MAE), Ecuador generates around 4.1 million tons of solid waste yearly, from which 25% correspond to recyclable products that include scrap, paper, cardboard, plastic and glass. The amount of solid waste generated daily per person increased from 0.57 in 2016 to 0.87 in 2017. The aggravating factor of this increase is that almost 96% of all waste, according to information from the National Institute of Statistics and Census is buried in local landfills or deposited in open dumps, despite the fact that the inorganic waste, when well classified and sorted, could be recycled for other use [2].

Waste management in Ecuador is still based basically in sanitary landfills, emerging cells, and open dumps, which ultimately generate large areas with accumulated garbage. and possible potential contaminants due to the chemicals generated by said waste [3].

On the other hand, waste cooking oil is considered as one of the most hazardous wastes because its improper disposal can cause significant environmental problems such as water pollution, soil pollution, marine ecosystem distraction, clog of drains, and consequently generates negative effects to the environment and results to an increase in water treatment cost [4]. One study done in Iran showed that 92% of the restaurants sell their edible oil waste (EOW) for poultry feeds without refinement. Most households (52%) throw EOW in the garbage and 21% dump their discarded oils in the sewage [5]. Another study made by the Secretary of the Environment of the Municipality of Quito (SEMQ) in 2014, found that only 50% of restaurants and businesses had a record of the amount of cooking oil that this sector purchases. With this information, the SEMQ inferred a consumption of about 10 million litres per year. Of this quantity, approximately 3 million litres are thrown away as waste, and only 50% is collected either by an environmental manager or by informal people who use this waste for animal feed [6].

By the year 2030, nations globally have set out to significantly reduce waste generation through prevention, reduction, recycling, and reuse activities. However, Ecuador is still very far from being able to meet this goal and no progress has been made until the report presented in 2019 by the General Secretary of the country, regarding the Sustainable Development Goals. To date, the MAE has limited itself to setting goals for motivational and encouraging purposes, but without concrete indicators to help achieve those goals.

The implementation of a circular economy would be seen as a viable response that would benefit the environment,

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companies, recyclers and citizens in general, since it would break the chain created by the linear economy in which waste is generated and cannot be reintegrated naturally into the environment. However, such a change is not only an economic challenge but more than anything a cultural one.

In this context, anaerobic co-digestion (AcoD) presents itself as a suitable and efficient technology for the biological breakdown of solid and liquid organic materials, and plays a vital role in renewable energy production. The organic materials are composed mainly of carbohydrates, proteins and lipids, which can be degraded to simpler compounds by anaerobic microorganisms in the absence of oxygen with the following process stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Anaerobic co-digestion has is a popular technology used to enhance the anaerobic digester´s biogas production, rather than mono-digestion of the same substrates. Biogas is a clean-burning "green" fuel used for heating and cooking, transportation and power generation. It usually contains about 55-60% methane, 30 – 35% carbon dioxide, and traces of hydrogen, nitrogen and other impurities.

The disposal of large amounts of food waste has caused significant environmental pollution and financial costs globally. Compared with traditional methods (i.e., landfilling, incinerations, and composting) anaerobic digestion is a promising technology for food waste management but has not yet been fully applied due to a few technical and social challenges. Additionally, waste cooking oil as a co-substrate can supply micro-nutrients and alkalinity, overcome the disadvantages in single digestion of food waste, more efficiently use equipment, and share cost by processing multiple waste streams in a single facility.

The objective of the preset study is to determine the potential biogas generation of food waste using waste cooking oil as co-substrate. Additionally, we search to know if using waste cooking oil indeed enhance biogas production. With this experimental research we intend to reduce the environmental impacts due to the final disposal of the most important solid and liquid organic wastes of a home, while generating renewable energy and reducing the need for burning fossil fuels that negatively affect the environment.

II. LITERATURE REVIEW

The final disposal of waste in the city of Guayaquil has been a very recurrent problem for the last 25 years. The management of both solid and liquid waste are the responsibility of the municipal government which, through public contracting contests, assigns a manager in charge of the collection, transport and final disposal of the waste generated in the city, management that is supervised by the Directorate of Cantonal Cleanliness, Markets and Special Services.

In the city of Guayaquil there is a production of 4,200 tons of garbage per day, which represents a relatively high figure compared to the cities of Quito and Cuenca with estimated values of 2,200 and 517 tons per day, respectively [7]. However, the figure varies proportionally depending on the number of inhabitants per city and these amounts could decrease with proper handling and proper classification of waste.

Another problem to the waste problem can be seen in the lack of culture for waste classification from the vast majority of citizens, turning harder the collection of the recyclables by the local informal waste pickers, who seeking daily sustenance, tend to damage the plastic bags in search of recyclable materials that generate a monetary value, giving a bad image to the neighborhoods.

The organic waste generated by the urban community of the city of Guayaquil is the product of daily consumption, development of commercial activities and daily activities. The composition of this waste can basically be divided into two groups: Organic waste, resulting from food preparation, which decomposes quickly, generates odors that are annoying for the community and attract urban disease vectors. And as a second group we have inorganic waste such as plastics, paper, glass, etc. These materials have a direct use as they can be recycled and reused in certain productive activities.

Obtaining biogas occurs through the process of anaerobic fermentation of fermentable components of the waste. This fermentation is produced by bacteria that develop in environments that lack oxygen. In the process of transforming organic matter (digestion) these bacteria produce a gas called "Biogas", which is mainly composed of methane (CH_4) and carbon dioxide (CO2) [8]. The biomethanation of organic waste is achieved through a series of biochemical transformations, which can be separated into a first step where hydrolysis, acidification and liquefaction take place, and a second step where acetate, hydrogen and carbon dioxide are turn into methane. In the first stage of the system, all the reactions take place simultaneously in a single reaction, while in the two or multi-stage system at least in two reactions [9].

Previous research has quantified, classified and characterized solid kitchen waste and waste cooking oil in the city of Guayaquil [10]. The energy potential of the city of Guayaquil was obtained after an analysis of the generation of urban waste and the use of residual oil and its different techniques for energy production and evaluation of its potential [11]. The determination of the production and calorific valuation of domestic waste as incineration potential would achieve notable benefits for energy efficiency and its use for electricity generation). This can be a benefit to the environment by avoiding the emission of methane (a greenhouse gas) into the environment, and the release of unpleasant odors that are generated by the decomposition of organic waste [12].

Methane production can be measured, taking into account a theoretical mathematical model for forecasting the volume of methane generated for an estimated period of time [13]. For the estimation of the energy potential of biogas, the following considerations can be taken into account: one ton of urban solid waste is capable of producing 60 m^3 of biogas with a proportion (60%) of methane (CH_4) and with a calorific value of 6 kWh/m^3 [14].

One of the most common artisanal methods used to carry out the biodegradation process are the well-known "biodigesters", in which a hermetically sealed container of any size or shape is used, where a mixture of substrates is deposited which will degrade obtaining biogas and other compounds. The type of reactor to be used in the experimental analysis is the bacht one or discontinuous type reactor, which consists of feeding the biodigester with a single load of organic mixture or batch, which after a period of fermentation time is then take to analyze the results over time to verify the production of biogas and its performance [15]. We should keep in mind that at the time of the experimentation there is no loss of gas through system leaks because this can affect the process of measuring the results [16].

A viable unit for the design of biodigesters due to its characteristics of simplicity and efficiency is to use a flexible structure, both for the transport of the units, redesign for capacity increase or future expansion of this, the design becomes relevant depending on the material to deposit [17]. Experimental biodigesters that use a hermetic closure according to [18], help to guarantee a high potential for biodigestion generation. The use of plastic bottles as reactors can result in a lower production than expected, however, it presents a good form for experimentation.

III. MATERIALS AND METHODS

For the experimentation, five glass containers were purchased, which, due to the purchase reference, showed that they could store 450 ml. To check the volume of the container, a 50ml syringe was used to fill it with water, taking the total volume reading of the container, which resulted in a total of 450ml (Figure 1).

Fig. 1 Volume check of the glass containers.

After, perforations were made on the lid of each of the containers, with a drill and a plastic pipe with an airtight valve were inserted and later sealed with cold welding (Figure 2).

For the verification of possible leaks and to check a hermetic closure of the lit, each closed glass jar was filled with air using a syringe and was submerged in water checking for bubbles (Figure 3). Once the verification of the hermetic closure was achieved, the samples of domestic solid waste and waste cooking oil were dosed in different percentages, as shown in Table 1, using for all jars 150 grams of solid organic waste as substrate and different values of waste cooking oil as co-substrate. All samples were obtained from previous projects done for the quantification of both domestic organic waste and waste cooking oil [19].

Fig. 2 Pipe passage and sealing.

Organic solid waste was grinded in a blender to homogenize the sample and after poured in the glass jars as shown in figure 4. After, waste cooking oil was poured in each jar, according to the percentages presented in table 1, as shown in figure 5. Finally, for a correct sealing of each of the glass jars, hot silicone was used to avoid possible leaks, as shown in figure 6.

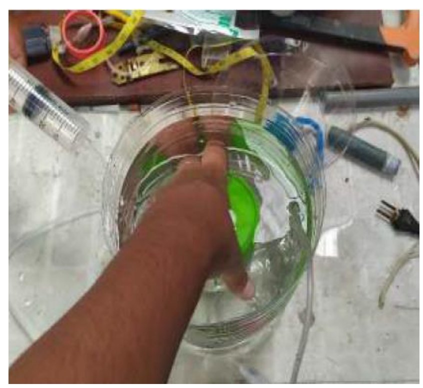

Fig. 3 Pressure test.

TABLE I
SAMPLE DOSIFICATION

Sample		Appearance	
	Substrate (grams)	Co-substrate (ml)	Co-substrate (%)
1	150	0	0
2	150	3	2
3	150	6	4
4	150	9	6
5	150	12	8

Fig. 4 Preparation of organic solid waste sample.

Fig. 5 Pouring of waste cooking oil.

For the data collection, periodic temperature measurements were made with the help of a pyrometer in periods of 12 hours for each of the jars. Pressure measurement was done using a manometer that was connected to a coupling at the end of the plastic pipes of each glass jar. Data was taken at the end of day 7 (Figure 6).

Finally, theoretical calculations were made to measure the methane generation of each jar at the end of day 14. First, the original mass of air was calculated using ideal gas equation No. 1.

$$m = \frac{PV}{RT} \quad (1)$$

Where

P = Atmospheric Pressure (101.3 kPa)
V = Volume of the Jar (300 ml)
R = Gas constant of air (0.287 kJ/kg*K)
T = Ambient Temperature (300 K)

Fig. 6 Sealing of artisanal biodigesters.

As a second step, we used the same equation, however using the final pressure of each jar. Following these, the mass of methane was obtained using equation 2.

$$m_{methane} = 60\%(m_f - m_i) \quad (2)$$

Fig. 6 Pressure measurement of glass jars.

IV. RESULTS

The initial mass of all 5 glass jars, considering equation 1 and data established in previous section was 0.3530 grams. Table 2 shows the amounts of methane generated for each of the samples in a retention time of 7 days, where it can be noted that sample 5 was the one with the highest generation (50.48 mg), followed by samples 1 (41.80 mg) and 4 (34.80 mg). The lowest value is presented by sample 2 with only 27,83 mg of methane generation.

TABLE II
PRESSURE AND METHANE MASS PRODUCTION

Sample	Pg (Bar)	Pabs (Bar)	mf (grams)	$m_{??ha??}$ (mg)
1	0.12	1.133	0.3948	41.80
2	0.08	1.093	0.3808	27.83
3	0.09	1.103	0.3843	31.32
4	0.10	1.113	0.3878	34.80
5	0.14	1.158	0.4035	50.48

The sample that had the most oil percentage generated the greatest amount of methane. One of the causes may be the large amount of organic matter present in the waste cooking oil as shown by the author Hidalgo-Crespo, 2019 where the characterization of residual cooking oil was detailed as: lipids in 99.19%, fatty acids 2 .98%, Volatile matter 0.38%. This could help to better understand how the use of waste cooking oil can increase the generation of methane.

V. CONCLUSIONS

Once the experimental analysis was completed, the following conclusions can be stated:

- The biodigesters were built based on the experimentation protocol. They were batch type and adapted with a hermetic system and a retention time of 7 days at a mesophilic temperature (between 25 and 35ºC), these being one of the optimal conditions. For the biodegradation we tried to keep environmental conditions constant to not affect the results.
- Functional low-cost biodigesters can be built, capable of producing methane to meet the demand of a home, helping to reduce the demand for fossil fuels.
- It was possible to obtain as a result that sample 5 with 8% of the mass of waste cooking oil generated a higher yield of CH_4 with a total of 50.47 mg., in a 450 ml container where 150 g of organic waste and 12 ml of waste cooking oil.

It is important to continue the evaluating of the methane generation potential of the different kitchen waste and its possible combinations with waste cooking oil, as potential sustainable energy projects in the city of Guayaquil.

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