Evaluación experimental de la co-digestión anaeróbica de contenido ruminal y estiércol bovino en un reactor rotativo

Experimental evaluation of the anaerobic co-digestion of ruminal content and bovine manure in a rotary reactor

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Abstract
Colombia is a country famously known for its biodiversity and high potential in agricultural production, Cordoba is a department labeled in Colombia for its high production of products that come from the field, the main economic activity in this place is livestock, then followed by agriculture. These activities leave organic residues such as manure and bovine rumen content, which can have a high energy potential. This research examined the behavior of anaerobic digestion and co-digestion, considering bovine manure (E) and rumen content (CR) as residual biomass. Samples with a ratio of 30% rumen content and 70% bovine manure (E70-CR30) and another complete with bovine manure (E100) were also evaluated. During the experimental evaluation, 2 samples were analyzed for E70-CR30 and another for E100 to analyze the parameters of pressure, pH and temperature, in addition to evaluating the behavior of biogas every week. As a last step, the biogas was characterized by means of a chromatography test to evaluate the calorific value (LHV) and to know the biogas yield. The results of the experiment showed that the E70-CR30 combination has a 64% higher CH4 production compared to the E100 mixture.

Keywords— Biomass, Co-digestion and Performance.

Resumen
Colombia es un país famosamente conocido por su biodiversidad y alto potencial en producción de agrícolas, Córdoba es un departamento etiquetado en Colombia por su alta producción de productos que provienen del campo, la principal actividad económica en este lugar es la ganadería, luego le sigue la agricultura. Estas actividades dejan residuos orgánicos como el estiércol y contenido ruminal bovino, que pueden tener un alto potencial energético. Esta investigación se examinó el comportamiento de la digestión y codigestión anaerobia, considerando el estiércol bovino (E) y contenido ruminal (CR) como biomasa residual. Asimismo, se evaluó muestras con una relación de 30% contenido ruminal y 70% estiércol bovino (E70-CR30) y otra completa de estiércol bovino (E100). Durante la evaluación experimental se analizaron 2 muestras para E70-CR30 y otra para E100 para los analizar los parámetros de presión, pH y temperatura, además de evaluar cada semana el comportamiento de biogás. Como última medida se caracterizó el biogás mediante un ensayo de cromatografía, para evaluar el poder calorífico (LHV) y conocer el rendimiento del biogás. Los resultados del experimento arrojaron que la combinación E70-CR30 tiene una producción de 64% mayor de CH4 en comparación con la mezcla E100.

Palabras claves— Biomasa, Codigestión y Rendimiento.

I. INTRODUCTION

Globally, energy projects are being developed with a political basis towards the development of the energy trilemma, which seeks to implement energy affordability, security and sustainability worldwide. This policy seeks to develop a synergy between energy creation and care for nature. [1]. In Colombia, biodiversity and energy potential abound in the environment, however, the use of this energy potential is being limited by not developing technological advances that can exploit these resources. According to the Mining and Energy Planning Unit (UPME), 71% of the energy production comes from hydroelectric plants while 28% comes from thermal energy and the remaining 1% is concentrated in alternative and renewable energies. [2]. In the same way, non-interconnected areas present only alternative energy consumption from organic waste or renewable energies, the technology commonly used for the exploitation of this energy is anaerobic biodigestion, which will be investigated in this study [3]. Anaerobic digestion is the process of biological decomposition of organic matter by means of batteries that are generated in the process of CH4 and CO2 production; the volume of biogas that can be generated depends on the type of biomass to be implemented in the anaerobic digestion process. [4]. To measure the efficiency of a biogas it is necessary to know its calorific value (LHV), this variable (LHV) is commonly used to evaluate the feasibility of using a given composition of solid waste as fuel [5].

A. Anaerobic digestion

In the development of different alternatives for energy generation, biomass has been found to be a sustainable supply for the coming years for the world's energy demand [6]. Biomass functions as a fuel in the process of anaerobic digestion, which involves different phases for the transformation of matter to energy. The first phase is known as hydrolysis, in which biomass has complex components such as carbohydrates, proteins and lipids that are broken down over time to form monomers that in turn degrade to initiate the next phase. Acidogenesis is known as the second phase of the process in which bacteria initiate the fermentation of the monomers produced, which initiates the degradation phase into short chains of propionic, acetic, hydrogen and carbon dioxide. The third stage of the process is called the acetogenic phase, in which the products collected in the acidogenic stage are used up as substrate for the rest of the microorganisms. This gives room for methanogenic bacteria that begin to convert them into substrates of volatile fatty acids, alcohols and methanogenic substrates. Finalizing the process initiates the production of two components CH4 and CO2 , this process is known as methanogenesis, which is shown in Figure 1 [7].

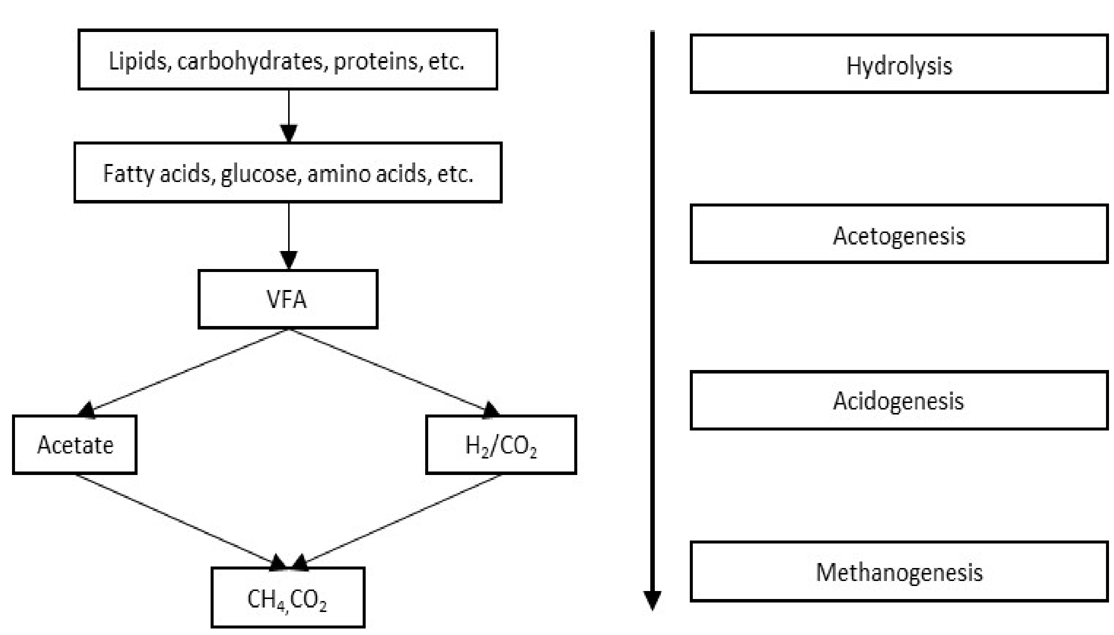

Fig 1. Four phases of anaerobic digestion [8].

B. Biomass

Biomass is considered to be the organic material that comes from all kinds of plants, such as trees, algae and crops. The way biomass is produced comes from the interaction between sunlight and plants through photosynthesis, including terrestrial vegetation, aquatic vegetation and organic waste. The energy that is stored in biomass is due to the chemical bonds that are formed in it, which thanks to digestion, decomposition or combustion, the internal energy can be released because its chemical bonds are broken. [9].

For biomass there are different variables to be considered for the selection of the energy conversion process such as the processing difficulties that may arise. In addition, biomass selection is also dependent on the form in which the energy is required. The main properties of this material, after processing as an energy source are :

1. Calorific value
2. Moisture content
3. Fixed and volatile carbon ratios
4. Ash/residue content
5. Cellulose/lignin ratio

C. Codigestion

Anaerobic co-digestion consists of the combination of organic wastes of different compositions in order to improve the chemical characteristics of the substrate as well as to improve the balance of nutrients it may contain. Likewise, this process helps to stabilize the system to induce the valorization of organic by-products. [10]

Thus, when creating a reactor for the anaerobic digestion process in agricultural production areas, we can select livestock waste together with organic waste from the food industry, in order to improve the performance of the process. Now, the literature shows us that organic industrial wastes usually have a high load of contaminants and at the same time contain high concentrations of saccharides, lipids, starches and proteins; which are rapidly degradable substrates. [11]

II. MATERIALS AND METHODS

For the design of the biodigester, the first thing that was taken into account is the method of biogas production and the materials that can function as a biomass reactor. Conventionally, plastic materials are used for the design of a biodigester, since they can withstand the chemical reactions generated by biodigestion and have low density. However, since the performance of the biodigester was to be measured according to the agitation of the process, plastic materials tend to deform with little stress, which was not feasible for the desired experiment. Therefore, an AISI / SAE 1020 steel was selected along with an anti-corrosive additive on the internal surface to prevent corrosion of the steel in the biodigestion process.

We implemented the use of 3 tanks with a capacity of 13.3 L, which used a ratio of 70% of its capacity for biomass and 30% of its capacity for biogas generation, the cylindrical design of Figure 2 was chosen based on the ease of rotation that can have the biodigester to evaluate the performance according to the agitation. From that, the biogas generated is evaluated by means of a chromatographic test in the Agilent Technologies 490 Micro-GC three-column machine, which is used under the ASTM E260-96 and ASTM D1945-03 standards.

TABLE 1.
ORGANIC MATTER IN EACH REACTOR

Contenido de materia orgánica			
Reactor	Masa de estiercol (Kg)	Masa de contenido R. (Kg)	Volumen (L)
E100	9,31	2,80	9,30
E70-CR30 I	6,57	2,80	9,30
E70-CR30 II	6,57	2,80	9,30

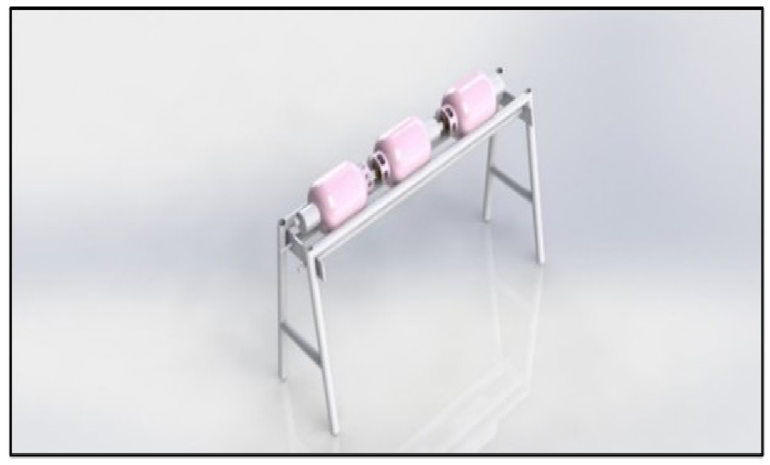

Fig 2. System diagram for reactors

The system that supported the biodigester provided agitation to the biomass it contained. For that reason, the first thing we did to collect data was to stop the rotating system for 15 minutes, in order to take samples of pressure, temperature and pH, respectively. To measure the pH of the biodigester, a valve was integrated into the biodigester, which was opened slightly to take the sample and store it at low temperature for later measurement. After that measurement, we were in charge of measuring the pressure directly from a manometer installed in the upper part where the biodigester is sealed. At the end, the temperature was taken by means of a thermocouple to the data acquisition system. After 42 days, a test was performed in the gas chromatograph and tests were carried out with the biogas generated. Determining and knowing the variables to be evaluated in the experiment are important to start the research development. In addition to taking into account the instruments used to measure the variables, as shown in Table 2.

TABLE 2.
INSTRUMENT TABLE.

Tabla de instrumentos	
Variable	Intrumento
Temperatura	Termocupla tipo K
Presion	Manometro
Balanza	Peso
Baeker	Volumen
Datos	DataloggerApplent
Composicion del gas	Cromatógrafo de gases
pH	pH-metro

A. Variables and equations

For this study, some chemical reactions are presented, which help us to generate the enthalpy of formation. Also, chemical reactions involving the conversion of biomass were studied. For example, combustion. For this research, different types of biomass were used using enthalpy of formation is calculated according to equation [12].

$$\Delta \mathrm{h} f_{298}{}^{\circ\,0} = 21.47C - 239.94H + 7.93S - 103.4O - 15.1N - 21.1A_{\mathrm{SH}} - 158.67H_2O \quad (1)$$

TABLE 3.
ELEMENTAL ANALYSIS FOR RUMEN CONTENT [7].

Analisis Elemental	
Carbono, C [%]	33,95
Hidrogeno, H [%]	4,80
Oxígeno, O [%]	36,50
Nitrógeno, N [%]	1,01

TABLE 3A.

PROXIMATE ANALYSIS FOR RUMEN CONTENT [7].

Análisis Próximo		
Determinacion	Base húmeda	Base seca
Humedad total [%]	11,96	
Ceniza [%]	20,52	23,31
Material Volátil [%]	54,73	52,16
Carbono Fijo [%]	0,38	14,53
Azufre [%]	0,38	0,43

However, it is necessary to know the proximate and elemental analyses of both biomasses in order to generate the enthalpy of formation, which is measured as kJ/kg. The values for this procedure should be handled in percentage, as shown in Table 4 and Table 4a [13]. On the other hand, we can infer by means of equation (2) of ideal gases [14], the amount of mass production being generated by the bioreactors.

$$P \cdot V = n \cdot R_u \cdot T \quad (2)$$

TABLE 4.

ELEMENTAL ANALYSIS FOR BOVINE ORGANIC MATTER [15].

Analisis Elemental	
Carbono, C [%]	44,65
Hidrogeno, H [%]	5,85
Oxígeno, O [%]	38,18
Nitrógeno, N [%]	2,05

TABLE 4A.

ELEMENTAL ANALYSIS FOR BOVINE ORGANIC MATTER [16].

Análisis próximo	Seco	Seco y sin cenizas
Carbono, C [%]	70,00	70,00
Hidrogeno, H [%]	8,96	-
Oxígeno, O [%]	16,93	18,60
Nitrógeno, N [%]	18,21	19,80

In addition, as new advances in the knowledge of the gases produced by the anaerobic digestion process are expected, it is necessary to consider the adiabatic flame temperature that each of the samples can have. Thanks to this value it is possible to know the maximum theoretical value of the products after combustion in a fully adiabatic reactor.

B. Composition of treatments.

To determine the components of the biogas produced by the biodigester, a chromatographic test was implemented to determine the percentage of CH4 produced in the anaerobic digestion. In this step of the investigation, a reference gas with 98.1% CH4 was used to determine the percentage of methane in our gas. Also, knowledge of the elemental composition of the organic material is essential to determine the theoretical efficiency of biogas combustion.

TABLE 4.

H70-CR30 COMPOSITION.

Tabla de procentaje en la cromatografia		
Componente	Fórmula	%
Metano	CH4	58,38
Dioxido de Carbono.	CO2	41,62

After evaluating the estimated time of each experiment, we were able to determine that the co-digestion of cattle manure and rice husks is the mixture with the highest biogas production in the process, as can be seen in Table 4. While the values in Table 5 show the composition of the anaerobic digestion of cattle manure (H100), which has a much lower percentage of CH4 than the co-digestion (H70-CR30).

TABLE 5.

H100 COMPOSITION.

Tabla de procentaje en la cromatografia		
Componente	Fórmula	%
Metano	CH_4	52,85
Dióxido de Carbono.	CO_2	47,15

The reference gas for the research was taken from the company Gases del caribe de Colombia, which uses this energy source to supply gas in the northern part of the country; this gas is treated to operate in special conditions since it needs a high efficiency to work in the primary consumption sectors of the country, such as vehicle, home and commercial.[17] The properties of this gas can be seen attached in Table 6.

TABLE 6.

COMPOSITION OF REFERENCE GAS (VEHICULAR GAS).

Tabla de procentaje en la cromatografia		
Cromatografia	Fórmula	%
Metano	CH_4	98,10
Dioxido de carbono	CO_2	0,11

III. RESULTS

The hypothesis used for this research is that anaerobic co-digestion can generate more biogas than anaerobic digestion of a single biomass, if and only if the right biomass is selected for the mixture. The first results of the experiment showed relevant data. For example, the pressure was the determining variable to know the biogas production with respect to the time of the experiment. Therefore, the first data taken were the pressures for the sample (E70-CR30 I), (E70-CR30 II) and E100.

For (E70-CR30 I) the total pressure was 10.89 kPa, while for sample E70-CR30 II it was 9.93 kPa. When comparing the results with the E100 sample of 6.07 kPa, we can infer that the manometric pressure increased as the anaerobic digestion time passed. Therefore, the biogas production is directly proportional to the reactor gauge pressure; likewise, by means of the gas law used in equation 2, the mass generated for the 3 samples was revealed, giving relevant findings that affirm our hypothesis, as shown in figure 3.

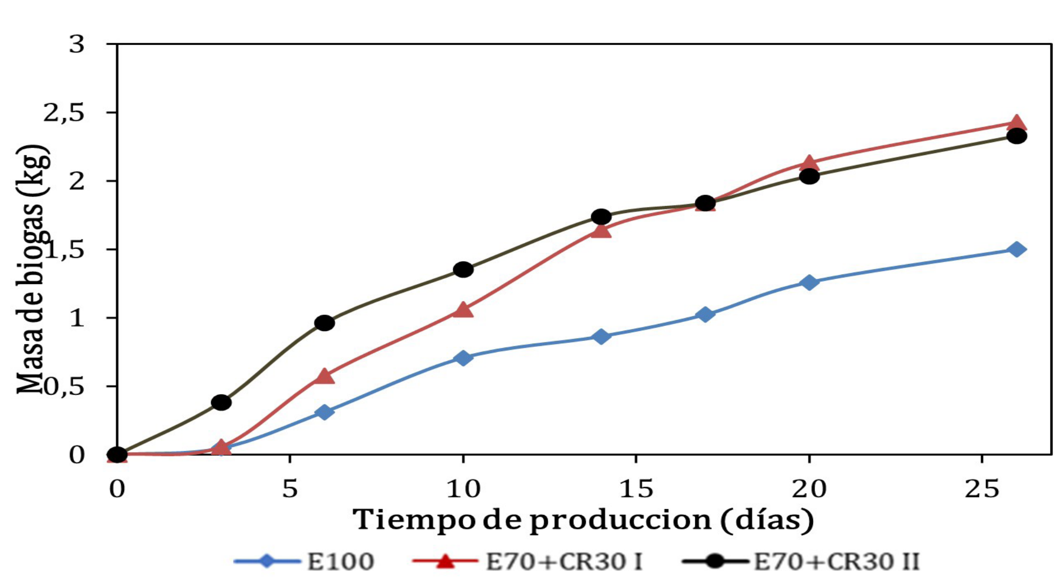

Fig 3. Mass record for the three reactors.

Similarly, the recorded pH variable shows us the beginning of a high percentage that leads to an acid state, this refers to the acid-genetic bacterial activity of the first stage of anaerobic digestion. After analyzing the behavior of several recorded data, we were able to reach a neutral zone and later an alkalinization zone, having a maximum value when we reached day 17 of the experiment, to end up later in a neutral zone as shown in figure 4.

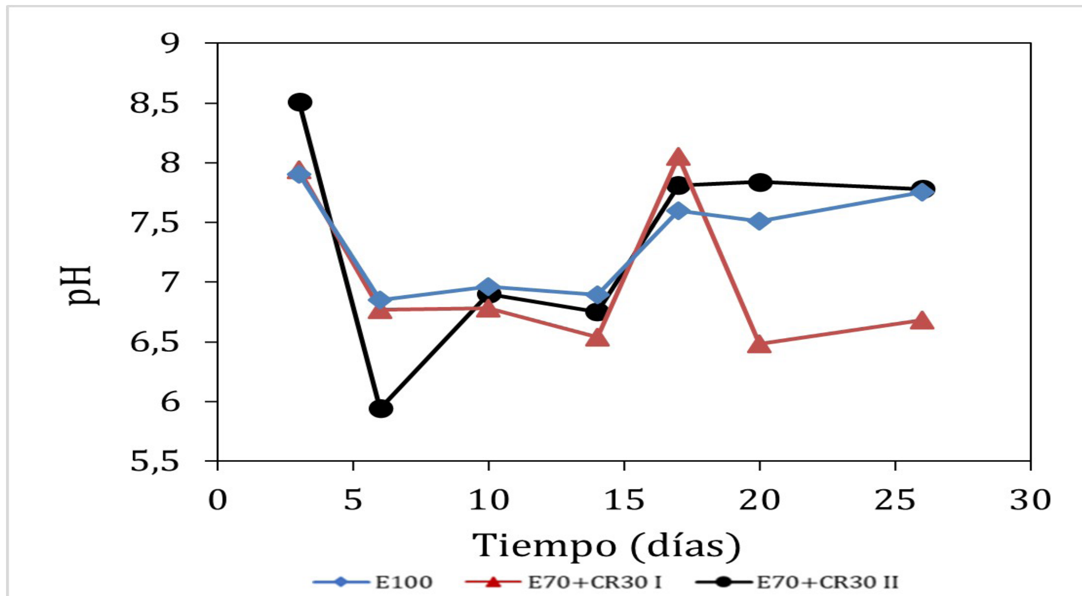

Fig 4. pH record for the three reactors.

In the process of anaerobic digestion there are different temperature ranges for its operation, the mesophilic temperature is known to be within a range between 35 to 37 °C and the thermophilic temperature manages a range between 55 to 60 °C. Conventionally anaerobic digestion works in the mesophilic range, however, in the thermophilic range a faster reaction and higher biogas production rate can occur.[18]

Having knowledge of the importance of temperature in the process of anaerobic digestion, the temperature of both substrates was measured during the experimental period as shown in Figure 5; to demonstrate that temperature increase and co-digestion influence the biogas production yield as stated in the literature. [19]

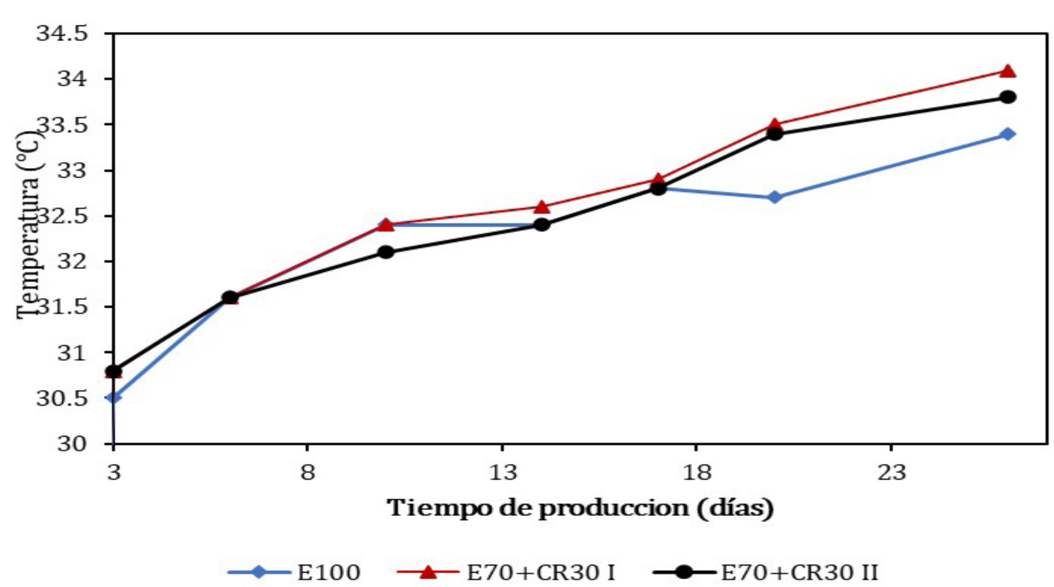

Fig 5. Scheme of the temperature record for the three samples.

After completing the experimental stage of the research, the data were processed to calculate the LHV variables and the adiabatic flame temperature. The results showed answers according to the hypothesis, according to Table 8, the E70-CR30 sample has better energetic properties than the E100 sample.

TABLE 8.

BIOGAS COMBUSTION PROPERTIES.

Tabla de procentaje en la cromatografia		
Biogás	Poder Calorifico LHV (Mj/kg)	Temperatura De flama adiabatica (°C)
E100	28,41	1812,00
E70-CR30	31,39	1832,00

In order to evaluate the credibility of the experiment, it was contrasted with works of other authors where the lower calorific value of biogas produced by anaerobic digestion is determined. The researcher Codignole and his team evaluated the biogas yield where the cattle manure had an anaerobic digestion phase for 15 days at a stable temperature of 37 °C; the LHV results were similar to the E100 sample of cattle manure since they were in the range of 25.8-26.9 MJ/kg [20]

IV. CONCLUSION

Within the different methods of energy conversion, residual biomass is one of the resources with the greatest potential for energy use, in addition to connecting different productive sectors such as agriculture, livestock and poultry for energy generation. In this research it could be concluded that the biogas generated from the mixture of manure and rumen content has better energetic properties; since the calorific value E70-CR30 increases 12% in comparison with the biomass E100. On the other hand, the adiabatic flame temperature has a percentage of 1.2% higher when we combine the rumen content with the bovine manure in comparison with only the manure mixture.

After the experimental time of 42 days, the co-digestion of biomasses (E70-CR30) had a higher pressure difference of between 60-80 % than the digestion of a single biomass (E100); in addition, the biogas generated from the mixture of rice husks and cattle manure obtained a percentage of CH_4 10.4 % higher than the exclusive use of cattle manure. Likewise, if we mention the pH variable, we conclude that the values obtained are very changeable, but remain in a neutral and acid state [5.5-9.0] throughout the experimental phase for the two samples treated.

In conclusion, the hypothesis that the cogeneration of biomasses can improve the energetic properties of the biogas generated, allowing a higher methane generation in our biogas volume is totally true, as long as biomasses that do not inhibit the energetic properties of the other are selected.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Samuel Bonilla-Gracia: Conceptualization, Methodology, Research, Validation, Writing - original draft.

Jorge Mendoza-Fandiño: Formal analysis, Resources, Supervision, Project management, Fund acquisition.

Jesús Rhenals-Julio: Visualization, Data curation, Writing - Review and editing, Software.

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