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Anaerobic Co-digestion Process Efficiency Estimation in Phases as an Alternative for Municipal Waste Treatment

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Abstract: The incorrect disposal of the waste generated in the municipalities contributes to water and soil contamination, resulting in a real concern in order to find an adequate disposal as well as obtain by-products that can be used to reduce CO_2 emissions. Anaerobic digestion turns out to be the most efficient treatment, both in environmental and economic terms. The objective of this study is to evaluate the anaerobic co-digestion process in phases as an alternative for the treatment of municipal waste: sludge from water treatment plants and the biodegradable part of Municipal Solid Waste (MSW), for three HRTs (Hydraulic Retention Times). Testing results show up a max elimination of 70.68% in VS (Volatile Solids) and 74.01% in COD (Chemical Oxygen Demand). With these percentages of elimination on average, 15.96 L/d of biogas was produced, for each kg of COD eliminated 0.56 m^3 of biogas was produced and for each kg of SV 0.85 m^3 and methane of 50.10%.

Key words: Co-digestion, methane, municipal waste.

1. Introduction

Currently one of the problems that threaten urban communities is the generation of waste, treatment and disposal. This problem is very significant in countries where, due to a lack of government politics for waste treatment investment, commonly municipal governments choose to use sanitary landfills with partial or no control (clandestine garbage dumps), these tend to lack protection systems for waste [1]. The soils in the face of the leachate from the waste and from any gas release containment system into the atmosphere, which represents gas pollution into the atmosphere, and in turn, a complete waste of the energy potential that these waste gases may contain [2-4].

There are a variety of alternatives for the treatment of waste, there have already been mentioned two of them used for the disposal of those [5, 6]. In this work we will focus on the treatment of MSW (Municipal Solid Waste) and residual sludge through the anaerobic co-digestion process in phases.

The system comprises a separation phase, an acidogenic phase and a methanogenic phase, achieving maximum efficiency on both processes [7, 8]. Important advantages include reduction of the volumes required for these processes, likelihood of doubling the digestion capacity of existing facilities, energy recovery, reduction of investments, reduction of maintenance and operating costs and improvement of management [9].

The future of anaerobic treatment of organic solid waste will take place within the framework of sustainable treatments since it offers several advantages [10]. Energy recovery: 100-150 m^3 biogas/ton of organic waste is important and, on the other hand, aerobic treatment of waste inevitably produces the emission of

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undesirable volatiles such as aldehydes, ammonia and even methane [11, 12]. Nowadays, the extraction of gas from sanitary landfills, which represents a great source of biogas generation, only allows partially recovering (maximum 60%) the gases generated, giving rise to an important methane mission to the atmosphere. According to Reyes (2018), the search for renewable energy alternatives and the reduction of greenhouse gases from the decomposition of organic waste recognize biogas a promising alternative for the substitution of fossil fuels as well for the energy recovery of waste organic in urban, rural and agro-industrial areas [13, 14]. Biogas is an attractive alternative energy source because of its decentralized energy availability, while its production is possible provided there are sources of organic origin [15, 16]. All these characteristics in this treatment have not gone unnoticed in the eyes of the first world countries, in countries of the European Union, especially Germany, England and France, are leaders in the use of this technology. For instance, in Germany the use of anaerobic digestion as a joint process with incineration represents 64% of its MSW treatment and disposal processes [17]. On the other hand, in anaerobic digestion, co-digestion is the term used to describe the combined treatment of various wastes with complementary characteristics, being one of the main advantages of anaerobic technology [9, 12, 18]. Recent work on co-digestion has focused on the search for synergism or antagonism between co-digested substrates [7, 19]. For example, optimizing the carbon-nitrogen ratio by co-digesting municipal waste and sewage sludge is noted as beneficial in methane production. The improvement in plug capacity is also reported as a positive effect on the process [11].

2. Materials and Methods

The pilot plant where the anaerobic digestion was carried out is in the Environmental Laboratory within the facilities of the Engineering Institute of the University of Veracruz, located at Veracruz-Boca del Río metropolitan area (Fig. 1).

2.1 Characterization of Municipal Waste to Co-digest

Two substrates were used for the preparation of the mixture to co-digest in our anaerobic co-digestion, sludge from a WWTP (Municipal Wastewater Treatment Plant), and the organic fraction of OFMSW (Organic Fraction of Municipal Solid Waste) from a restaurant complex.

Considering previous works for the calculation of the daily volumetric load, the volume of the reactors was taken into consideration, since each one has a capacity of 40 L, it was decided to take a maximum of 3⁄4 of the total. In addition, according to IDAE, 2007 due to the high rates of acidogenic bacteria, the retention times of each reactor must be accurately controlled. The ideal was to occupy a volume of 30 L for the methanogenic phase, and since they wanted to operate during a short time, 20 days were chosen as HRT (Hydraulic Retention Time) and therefore a volumetric load of 1.5 L⁄d was obtained. Samples of 250 mL were estimated to carry out the determinations, comprising a total of 1.75 L of substrate to feed in the acidogenic phase with an HRT of 11 days. Make a total of 31 days of HRT of the process and they were sampled for 3 HRTs. Taking as reference the study [1], they explain that anaerobic digesters can be considered high load if the TS (Total Solids) concentration ranges

Fig. 1 Pilot plant of the anaerobic digester in phase.

between 22-28 kg/m^3. It was decided to feed 25 ± 2 kg/m^3 of TS.

2.1.1 Plant Sludge

The residual sludge is obtained from a WWTP in the metropolitan area. It is thickened in the Environmental Engineering Laboratory until it has a concentration of 0.25 g/L of sludge. The pH, temperature, TS, VS (Volatile Solids) and COD (Chemical Oxygen Demand) are determined (Fig. 2).

2.1.2 Organic Fraction of Urban Solid Waste

The OFMSW sample is prepared from organic waste from a restaurant complex; this organic matter is ground (Fig. 3) and mixed with water until a concentration of 0.25 g/L of organic matter is obtained.

Fig. 2 Thickening of sludge.

Fig. 3 Organic fraction grinding.

After that, 9 L of the diluted OFMSW is stored. As with WWTP sludge, the OFMSW is tested for pH, temperature, TS and VS. In addition to moisture and ash tests to determine its percentage of carbon and organic matter, these last 2 tests are important to carry out on the organic fraction because it contains most of the organic matter to be digested from the mixture, compared to sludge from the WWTP that its organic matter content is not as significant as that of the OFMSW.

The OFMSW-sludge mixture is prepared with a 1:1 ratio, as seen in Fig. 4.

2.2 Operation Parameters

The operating parameters established for the two different phases, to ensure an ideal process, are summarized in Tables 1 and 2.

Once the mixture was obtained, it was proceeded to feed daily. In Fig. 5 shows the feeding procedure of the digesters and in Table 2 the periodicity of the sampling and the techniques use.

Fig. 4 OFMSW-sludge mix.

Table 1 System operating parameters.

Conditions	Acidogenic reactor	Methanogenic reactor
Temperature	-	30-38 ℃
pH	Acid	6.5-8
Trading volume	20 L	30 L
Volumetric load	1.75 L	1.5 L
HRT	11 d	20 d
VFA's	-	Less than $0.5 \frac{kg}{m^3\ CaCO_3}$
TS	25 ± 2 kg/m^3	-

Table 2 Sampling periodicity.

Substrate	Parameter	Method	Frequency
OFMSW	Moisture, organic matter, volatiles, and ash	Analytical techniques (Miguel A. Gómez Nieto and Ernesto Hontoria García)	Once a week (1 per batch)
Sludge	TS, VS, COD	Standard methods (APHA-AWWA-WPCF) [20]	Once a week (1 per batch)
OFMSW-sludge	TS, VS, COD	Standard methods (APHA-AWWA-WPCF) [20]	Three times a week (3 per batch)

Fig. 5 Sampling process.

2.3 Biogas

The biogas production began to be observed from the second HRT of the methanogenic reactor from the beginning of its feeding (20 days for this phase), being the pH conditions neutral and maintaining a temperature of 35 °C. The biogas analysis presented in this study only covers 2 HRTs (corresponding to 62 days of production).

2.3.1 Obtaining Biogas

A stainless-steel gas line was adapted to the methanogenic reactor. The volume obtained was measured by water displacement.

2.3.2 Sampling

To achieve an adequate amount of biogas inside the methanogenic bioreactor, and thus obtain a significant sample, previous tests were carried out during a week, consisting of the following: The valve connecting the reactor with the storage tank was closed for a period of two, three and four hours. After said time, the valve was opened and the volumes obtained from biogas during the different periods were recorded. After this test, it was decided to choose the option of 2 h for the retention of the biogas, since it turned out to be a short period of time where a sufficient volume production was obtained to carry out the sampling (Fig. 6).

Fig. 6 Biogas sampling.

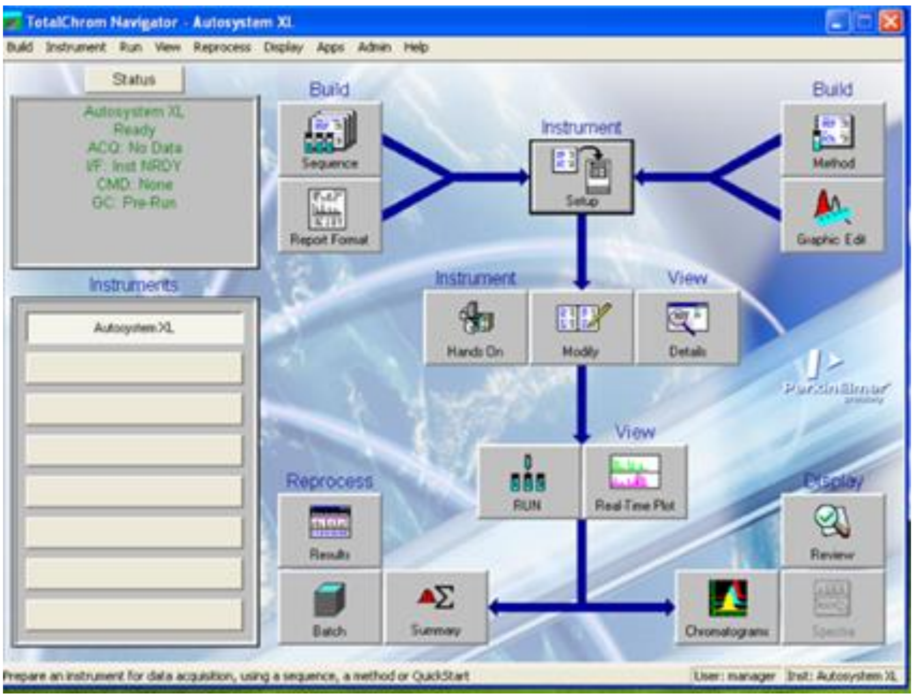

Fig. 7 Screen indicating that the equipment is ready to start the run.

It began with the biogas sampling from the fourth HRT, having a constant production volume. Samples were taken by connecting one end of a flexible hose to the valve of the gas sampling bag and the other to the sample outlet nozzle.

The biogas analysis and the quantification of the methane content were carried out by means of a gas chromatograph from the PerkinElmer brand using the Turbochrom software (Fig. 7). An Elite-Plot Q capillary column was used as it is excellent for separation of

Table 3 Operational parameters.

Parameters	Value
Injection volume	1 mL
Holding time	1.66 min
Run time	4 min
Inyector temperature	220 ℃
Oven temperature	50 ℃
Detector temperature	250 ℃

gaseous compounds at room temperature, which has a length of 30 mm and a capillary diameter of 0.32 mm. According to the requirements of this equipment, the gases used for its operation were three: nitrogen, hydrogen and compressed air. Hydrogen and compressed air are the gases used to start the ignition process of the detector flame with a ratio (1:10), while the function of nitrogen is to be the carry gas. The detector selected was of the FID (Flame Ionization Detector) type as it turned out to be suitable for the recognition of CH_4. The parameters to carry out the diagnosis are those shown in Table 3.

3. Results and Discussion

With an average pH of 7.2 and a temperature of 31.3 ℃, it was possible to reach the mesophilic conditions required for the proper functioning of the system in this phase. Three HRTs were considered. Feeding loads were 1.29 kg TS/m^3 d and 1.63 kg COD/m^3 d. The average achieved in the elimination of organic matter measured as TS was 51.85%, for the VS of 57.85% and COD of 59.16%, managing to observe that the 3 elimination percentages were greater than 50%. The VFA's/Alkalinity ratio was 0.13 on average; this factor is the best indicator of the process situation, since the pH will change when the buffer capacity of the system has already been broken. In general, it is considered that a digester is in optimal conditions when VFA's/Alkalinity ≤ 0.5. Table 4 shows its maximums and minimums, as well as the average values obtained in the general phase co-digestion system.

In Fig. 8, the evolution of the elimination of organic matter measured as COD is shown and some stabilization is observed from day 52. In Fig. 9, the behavior of the percentage of elimination of organic matter measured as SV with a behavior like the elimination of COD is observed.

Once the system was stabilized, in addition to evaluating the TS, TVS and COD parameters, the amount of biogas produced (flow, biogas produced based on COD_{remov} and TVS_{remov}) was analyzed. The Table 5 shows the mean values of the biogas produced evaluated during the 4 established HRTs.

Table 4 Average values of the process in phases.

Parameter	Inlet			Outlet		
	Mean	Max.	Min.	Mean	Max.	Min.
ST ($\mathbf{kg/m^3}$)	25.76	27.34	23.00	12.36	13.71	9.58
STV ($\mathbf{kg/m^3}$)	21.88	23.85	19.30	9.19	10.78	6.68
DQO ($\mathbf{kg/m^3}$)	32.65	40.00	27.57	13.27	16.55	10.69
pH	-	-	-	7.2	7.5	7.0
Temperature (℃)	-	-	-	31.3	38.0	21.5
A ($\mathbf{m^3 \cdot d}$)	0.00175	0.00175	0.00175	-	-	-
RHT (d)	31	31	31	31	31	31
% TS elimination	-	-	-	51.85	63.91	42.06
% VS elimination	-	-	-	57.85	70.68	46.82
% COD elimination	-	-	-	59.16	74.01	50.73
Power load ($\mathbf{kg\ TS/m^3 \cdot d}$)	1.29	1.37	1.15	-	-	-
Power load ($\mathbf{kg\ TVS/m^3 \cdot d}$)	1.09	1.19	0.97	-	-	-
Power load ($\mathbf{kg\ COD/m^3 \cdot d}$)	1.63	2.00	1.38	-	-	-
VFA's/Alkalinity	-	-	-	0.13	0.19	0.11

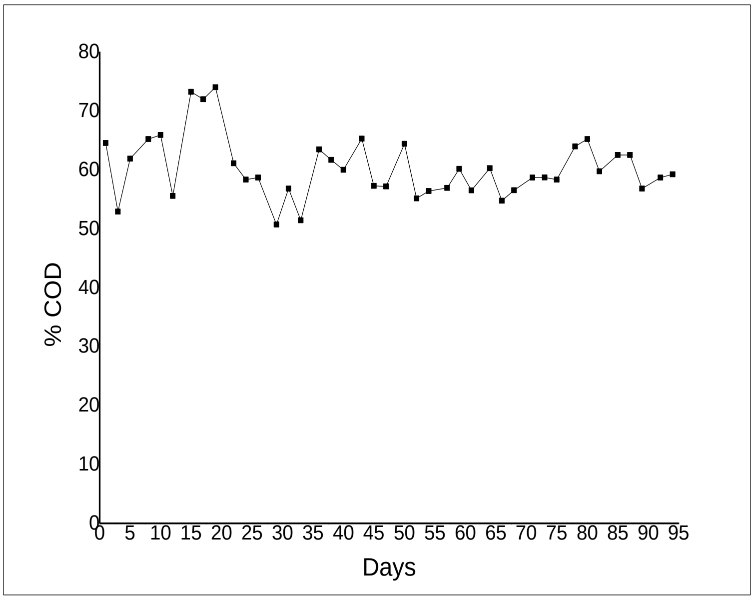

Fig. 8 Evolution of the COD of the system in phases.

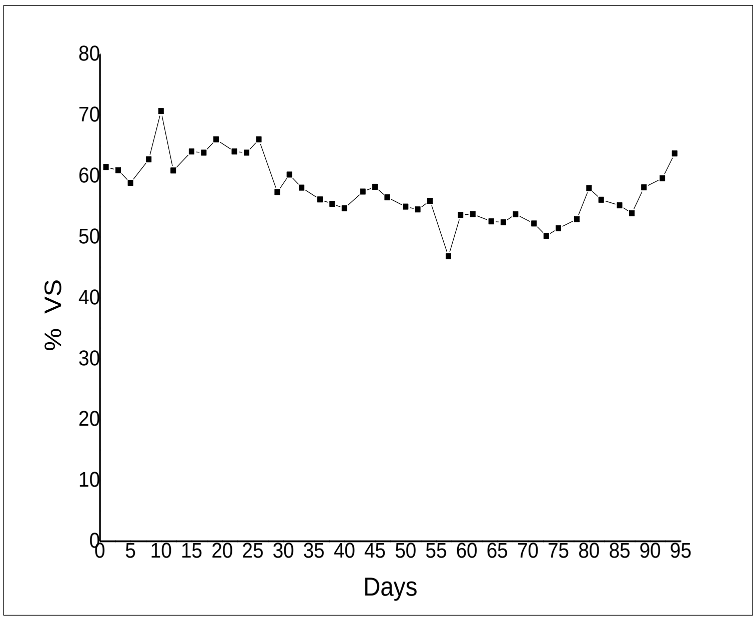

Fig. 9 Evolution of VS in the system in phases.

Table 5 Average values obtained from biogas.

Parameter	Mean	Max.	Min.
Biogas (L/d)	15.96	21.00	10.00
Biogas ($m^3/kg\ COD_{elim}$)	0.56	0.81	0.32
Biogas ($m^3/kg\ TVS_{elim}$)	0.85	1.21	0.48

In Fig. 10, it shows the biogas volume, which registers an average of 15.96 L⁄d, a maximum production of 21 L⁄d between 102 and 106 days and a minimum of 10 L⁄d in the first days of the study. A constant flow can be observed from day 15 to 76 with values between 15 L⁄d and 18 L⁄d and only a minimum value of 12 L⁄d registered in that range. From day 90 to 120, the highest biogas values were obtained.

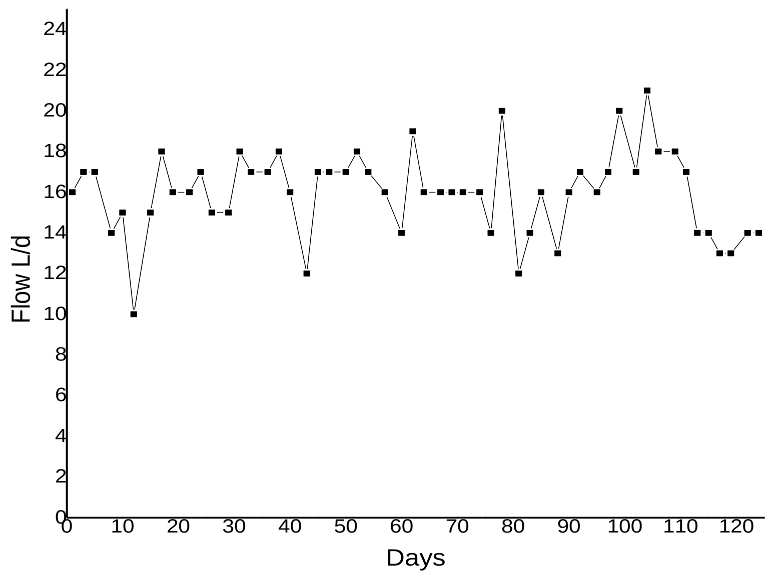

Fig. 10 Volume of biogas produced.

The biogas production calculated based on the COD removed was 0.56 m^3/kg on average and based on the VST removed it was 0.85 m^3/kg. The evolution of these parameters can be observed in Figs. 11 and 12 where a series of similar fluctuations are presented in both graphs, which indicates certain stability in the process. In addition to this, a considerable decrease in the percentages of COD and VTS remove can be noted on days 12, 43 and 81 that compared to Fig. 10 of the volume of biogas produced. This decrease also coexists, and this fact reinforces the importance of these parameters to evaluate an anaerobic digestion system, as they affect biogas production.

Table 6 shows the mean CH_4 values obtained from phase co-digestion and Fig. 13 shows the fluctuations.

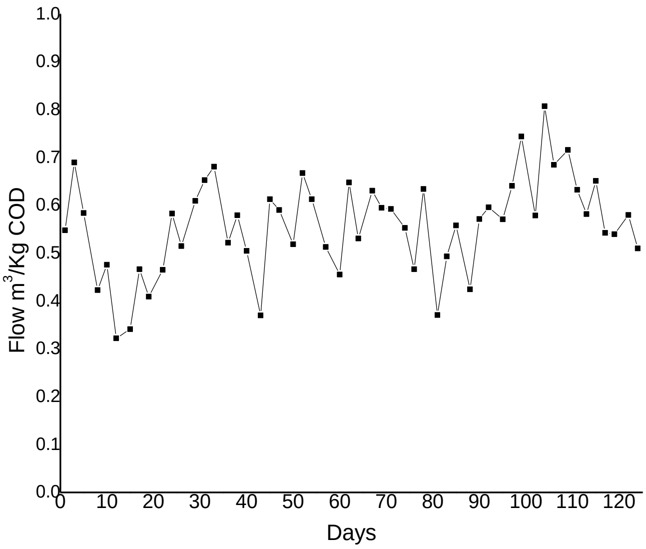

Fig. 11 Biogas flow measured as m^3/kg of COD removed.

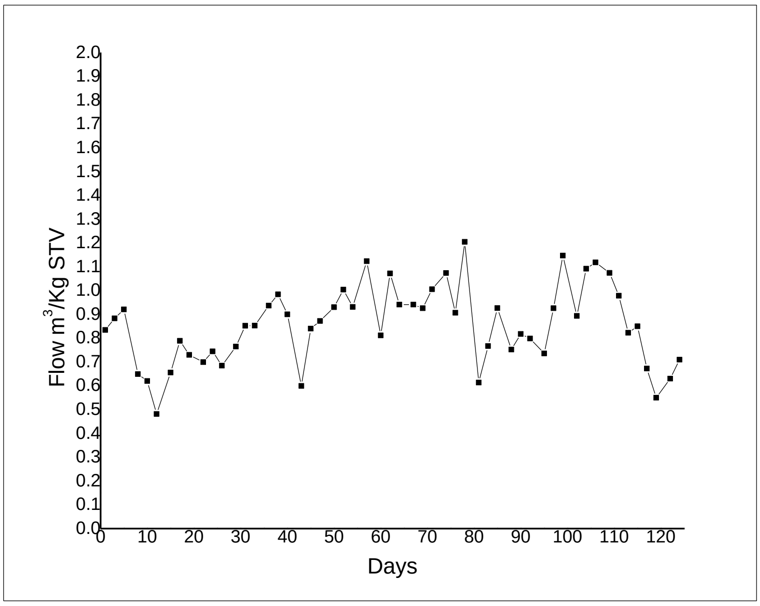

Fig. 12 Biogas flow measured as m^3/kg STV removed.

Table 6 Mean values of percentage of methane.

Parameter	Mean	Max.	Min.
% CH_4	50.10	71.36	22.74

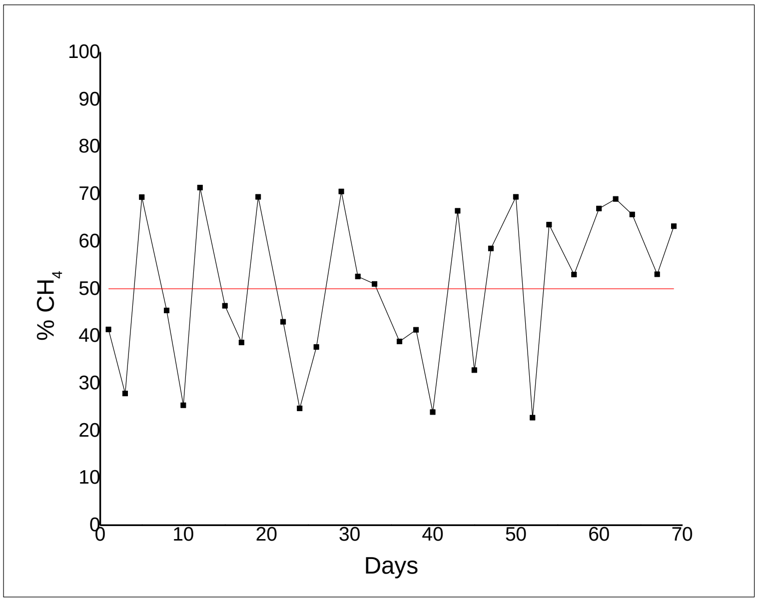

Fig. 13 Development of the co-digester methane volume in phases.

4. Conclusion

For anaerobic digesters in phase co-digestion, fed with a sludge-OFMSW mixture with a 1:1 ratio and an average feed load of 1.29 kg TS/m^3 d and 1.62 kg COD/m^3 d, at an average temperature of 30 ℃ and pH of 4.6 for the acidogenic phase; 31.3 ℃ temperature and 7.2 pH for the methanogenic phase and three HRTs. A general average removal is obtained, and a biogas production of TS with 51.85% removal, VTS with 57.85% removal, COD with 59.16% removal. Biogas was obtained in relation to the

COD_{remov} of 0.56 m^3/kg, in relation to the TVS_{remov} 0.85 m^3/kg and average of 15.96 L/d. The average methane percentage was 50.10%. These values reflect the fact that the anaerobic co-digestion in phases of two substrates of different origin, obtains a removal of organic matter greater than 50%, which allows the generation of an energy product such as biogas, in addition to a biosolid usable.

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