ANAEROBIC CO-DIGESTION OF SOLID ORGANIC WASTE AND SHEEP MANURE FOR BIOGAS PRODUCTION

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Abstract

Anaerobic co-digestion of the organic waste with animal manure is an efficient alternative to treat and reduce the waste and contaminants. It improves the performance of biogas production and also obtains other by-products beneficial to the environment, like organic fertilizers. In this study, we analyzed the effectiveness of degradation of the organic matter through anaerobic co-digestion of the sheep manure and organic waste in batch reactor at a temperature of around 28º C at different proportions of the mixing composition. These results showed a direct relation between the biogas production and, physicochemical and bromatological characteristics. The kinetics of biogas production was characterized as a function of Biochemical Methane Production (BMP) in a batch mode. It was used batch bioreactors in glass jars with a capacity of 250 ml at room temperature. The pre-treated substrates (organic materials) were incubated with the inoculum containing a variety of anaerobic microorganisms in a suitable medium (water and minerals). The substrate was added to a medium that serves as a source of carbon and energy for microorganisms. After incubation, the degree of degradation was measured as the daily BMP (biochemical methane production) until the digestion process was finished. The anaerobic co-digestion showed a significant biogas production. The analytical results indicated that the anaerobic co-digestion of solid organic waste with different fractions of sheep manure, resulted in a high biogas yield in comparison with the pure digestion of farm animal manure.

Key words: anaerobic digestion, biogas, organic fertilizers, methane, manure

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Introduction

Municipal solid waste (MSW) is consisted of organic and inorganic matter, and is generated in business, industrial and house-hold activities, among other sources. This organic fraction of municipal waste that is sorted in central plants or the organic fraction, which is separated, refers to bio residual (vegetable, fruit and garden waste) (Garcia, 2011). These are produced in considerable quantities mainly in agricultural activities, supermarkets and markets, which have additional costs for separation, transport and disposal (Scano et al, 2014).

The livestock industry is another source of organic waste such as manure. In Mexico the number of sheep heads registered until 2014 was 8.6 million.

Landfills are the sites most used to receive so much organic and inorganic wastes generated in Mexico, however without a good operation it can cause environmental impacts, such as air pollution due to green house gas emission, contamination of pathogens and harmful compounds through leachates (SENER, 2012). To avoid these effects, there is the alternative as a different destination for the organic fraction using anaerobic digestion, which is a biological process that converts organic matter into a mixture of carbon dioxide and methane through a complex process using microorganisms (Gao et al, 2016), and has a number of benefits, including reduction in solids , odor reduction, and reduction of greenhouse gas emissions (Naji et al, 2016a).

There have been several studies of anaerobic treatment for this type of organic matter and biogas generation where it was observed advantages in combining two or more substrates which is referred as anaerobic co-digestion. In addition, co-digestion of various organic wastes for energy production has taken interest recently since it offers important advantages such as: the dilution of toxic compounds, improving the balance of nutrients in the system. It provides a synergistic effect of microorganisms and increases the burden of biodegradable organic matter improves the performance of production of biogas (Naji et al, 2016b).

Studies where it is compared an anaerobic digestion with a single substrate (organic waste or other substrates) and the anaerobic co-digestion which analyzes solid reduction, removal of COD (chemical oxygen demand) and methane with BMP production yields. Results show that the co-digestion of organic waste and other substrates improve methane production compared to the digestion of one of the substrates such as food waste, organic fraction of municipal waste, rice straw, activated sludge and manure from dairy cattle, (Ebner, 2016 et;) Et Moñino, 2016; Naji et al, 2016b; Naran et al, 2016; Poulsen et al, 2016; Wickham et al, 2016; Et Astals, 2014; Gou et, 2014; Garcia et al, 2011).

This paper analyzes the effectiveness of an anaerobic co-digestion of sheep manure with organic waste for the decrease of the volume of organic material, add a value to the organic waste thanks to the production of methane and prevent negative impacts on the environment and human health.

Anaerobic digestion (DA) is a biological process carried out in the absence of oxygen in which organic matter is metabolized by a variety of microorganisms with the production of biogas (about 50-75% methane and 50 - 25% carbon dioxide) (Michalská et al., 2015;) Mata-Alvarez et al., 2014). Producing methane makes this process an energy producer rather than an energy consumer, other advantages of anaerobic treatment process are: its lower power consumption, lower sludge production, lower requirements of nutrients, as well as provide a rapid response to the addition of substrate after long periods without food (Metcalf and Eddy, 2003).

Anaerobic digestion is a balanced ecological system, where different populations of microorganisms perform specialized functions and the decomposition of organic compounds is considered to be a two-step process. In the first stage, a group of facultative bacteria and anaerobic bacteria convert (hydrolysis and fermentation) the compound's organic complexes (carbohydrates, proteins and lipids) into simple organic materials, mainly volatile fatty acids (AGVs), as well as carbon dioxide and hydrogen gas. In the second stage, organic acids and hydrogen are converted into methane and carbon dioxide; this conversion is performed by a special group of microorganisms called methanogens, which are strictly anaerobic. While anaerobic digestion is usually considered to be a two-step process, this can be divided in several metabolic pathways, with the participation of several microbial groups (de Lemos, 2017) as shown in figure 1.

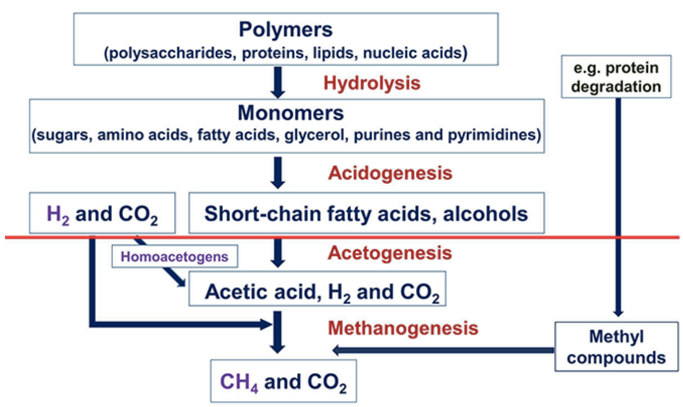


Figure 1. Biochemical stages in the anaerobic digestion

ANAEROBIC CO-DIGESTION

The anaerobic co-digestion is a process where two or more substrates are mixed with complementary characteristics for combination therapy. The co-digestion has been reported as a viable solution to overcome the inhibition by ammonia and short chain fatty acids and to improve the production of methane. Different substrates such as biological waste (Astals et al, 2014), food residues (García, 2011) Naran et al, 2016), plant debris and manure (Yong et al, 2015) have been used. Within the characteristics of the fruit waste and vegetables have a high content of organic matter readily biodegradable (75%) (Garcia et al, 2011) as well as higher total volatile solid content than other wastes (Fantozzi and Buratti, 2011). Regarding the use of manure, which has a high buffer capacity and high in nitrogen, as well as which contains a variety of nutrients for bacterial growth (Li et al, 2016) are characteristics that help the stabilization of an anaerobic system.

Another substrate used in the anaerobic co-digestion is activated sludge (Nara net, 2016), these are characterized by the relative low C/N ratio but with high capacity of buffer (Astals et al., 2013), therefore is able to tolerate co-substrates with large quantities of easily biodegradable organic matter and low alkalinity values (Dai et al, 2016).

BIOCHEMICAL METHANE POTENTIAL (BMP)

BMP is a technique useful in laboratory scale to assess the conversion of organic waste to CH4. The experimental value of BMP is given as CH4/g VS ml added to the reactor (Sanchez et al, 2016), but can also be expressed in m3CH4/m3 sample, ml CH4 / Kg sample or ml CH4 / kg COD added (Owen et al, 1979).

The BMP test results can be used to determine the biodegradability of substrates under anaerobic conditions, and therefore relative dwelling times required for complete digestion (Elbeshbishy et al, 2012). Therefore the formula for the calculation of BMP could be as follows

$$BMP = \sum_{n=1} \frac{X_n}{S}$$

where BMP is the biochemical methane potential, X is the daily production of methane, n is the unit of time and S is the amount of initial substrate of the sample added.

Materials and methods

1. Specimen collection and preparation of waste SM, RIER, MM
2. Physicochemical characterization: pH, COD, TS and TVS

3. Bromatological characterization: humidity, ashes, TKN, carbohydrates, lipids, and fibers.
4. Experimental design in the proportions of mixtures PM-RIER and PM-MM: 70:30, 50:50, 30:70, based on percentage of COD.
5. Installation of 300 ml batch hermetic reactors
6. Monitoring of pH, COD, ST, STV, TKN, (before and after 43 days of digestion).
7. Daily measure of volume of he methane generated.

Characterization of waste

It was determined the bromatological and physicochemical composition of the inoculum, manure, organic waste of IER and MM. The characterizations were done according to the rules and methods referred to in table 2 and table 3.

pH: Measured with a reagent strip

COD: The sample was reacted with a digestive solution composed of a strong acid with excess of potassium dichromate. The sample that has not been reduced was measured in a spectrophotometer. Finally, it is estimated the oxidizable matter in terms of equivalent oxygen (NMX-AA-030-SCFI-2001).

TOTAL SOLIDS (TS): by Gravimetry. Solids dried at 103 ± 2° C (NMX-AA-034-SCFI-2001).

TOTAL VOLATILE SOLIDS (TVS): by Gravimetry. Solids dried at 103 - 105° C and incinerated at 550° C. The VS were determined by difference with respect to the weight loss (NMX-AA-034-SCFI-2001).

FIBER: The previously calcinated sample was digested in acidic and alkaline media and the crude fiber was obtained by difference in weight (NMX-F-090-S-1978).

LIPIDS: Cyclic extraction of hexane-soluble constituents (NMX-F-089-S-1978).

ASHES**:** by Gravimetry. Solids dried at 103 - 105° C and incinerated at 550° C. The ashes were determined by the weight of them remaining in the crucible (NMX-AA-034-SCFI-2001).

HUMIDITY: by Gravimetry, which is obtained by the difference between the initial weight and the total solids (APHA 2540 B).

TOTAL KJHELDAL NITROGEN (TKN): The sample was digested in acid medium and later titrated.

PROTEINS: Coefficient of conversion (6.25) in accordance with the measurement of the TKN (Ebner et al, 2016).

Installation of reactors.

The batch type reactor of 250 ml capacity was mounted as shown in figure 2, which had a cover with outlet as shown in the figure and adapted to maintain a watertight system. It was considered a useful volume of 200 ml, the remaining space for the generated gas.

For the preparation of the mixture was done as follows: It was added 1.5 mg/L of inoculum, value recommended by Parra (2015), 1 ml and 2 ml of a solution of macro and micronutrients respectively and 3.5 g/l of a mixture of the organic waste and sheep manure, considering the proportions described in table 1 and taking into account the values suggested by Aguilar (2015). The pH was stabilized at pH 8 with 3N NaOH to give stable pH conditions at the beginning of the tests. The reactors were maintained at temperature between 25 and 28 °C.

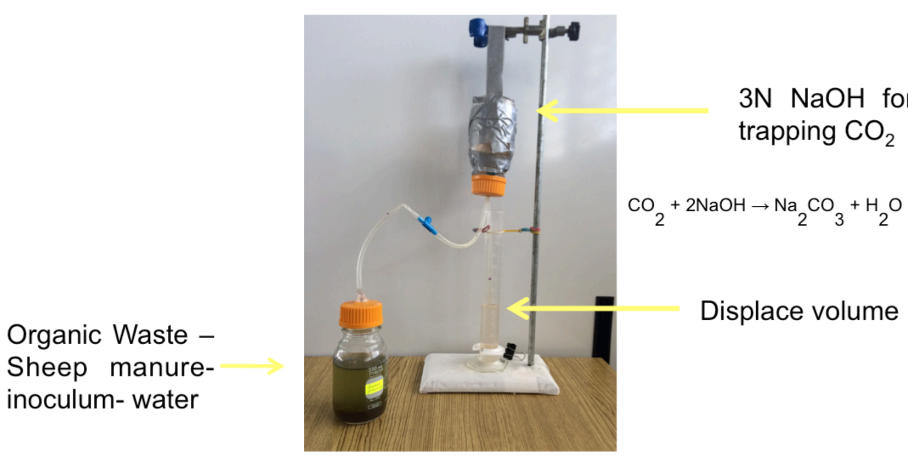


Figure 2. Batch type reactor

No. Bioreactor	SUBSTRATES CONTENT
1	Inoculum 100%
2	Sheep manure (SM) 100%
3	Municipal Market waste (MM) 100%
4	Urban organic waste (RIER) 100%
5	SM-MM 70:30
6	SM-RIER 70:30
7	SM-MM 50:50
8	SM-RIER 50:50
9	SM-MM 30:70
10	SM-RIER 30:70

Table 1. Proportions in each reactor

The proportions of mixtures in the treatments are shown in table 1.

RESULTS AND DISCUSSION

The waste characterization results (bromatological and physicochemical characterization) of organic waste of IER and MM, SM and sludge used as inoculum are shown in table 2.

Substrate	RIER	MM	SM	Inoculum
COD (g/L)	122.09	91.59	312.25	24.11
pH	3.66	3.92	9.46	6.96
TS (g/L)	157.60	117.97	367.87	37.6
TVS (g/L)	146.63	111.2	283.63	18.37
TVS/TS	0.93	0.94	0.77	0.49

Table 2. Values of physicochemical parameters of waste

Bromatological characterization results of substrates are shown in table 3, where lipids, fibers, TKN, ash and protein were determined on a dry basis, so carbohydrates were calculated by the difference regardless of moisture, using the following formula:

Carbohydrate = 100%-% lipids - proteins - ash % (FAO, 1999).

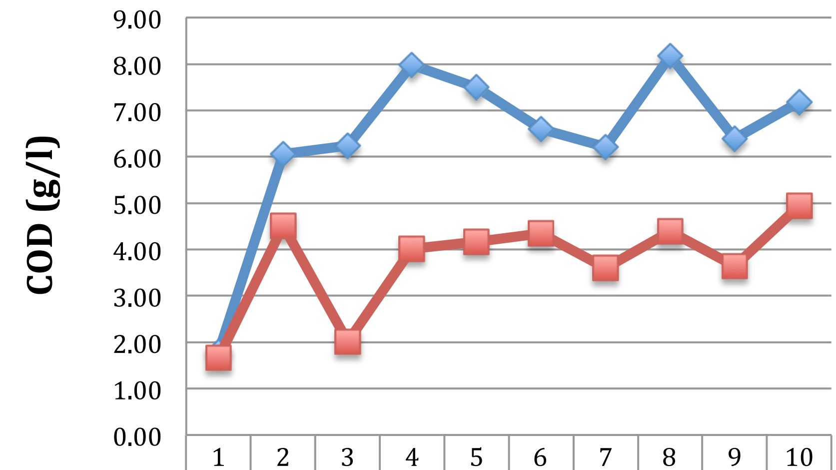
Substrate	RIER	MM	SM	Inoculum
Lipids (%)	6.65	2.42	14.37	NA
Fiber (%)	9.96	8.37	18.05	NA
TKN (%)	2.61	2.13	2.91	4.73
Protein (%)	16.19	21.10	18.52	28.82
Carbohydrates (%)	70.20	70.74	44.21	NA
Humidity (%)	84.24	88.2	26.28	96.28
Ashes (%)	6.96	5.74	22.90	NA

Table 3. Values of bromatological parameters of waste

From the data shown in table 2, it is evident that there are some differences in the composition of the organic waste. RIER had the COD, TS and TVS values higher than that of MM. In the case of the sheep manure, the values of COD, TS and TVS are the highest. Another outstanding characteristic is that the organic wastes show acidic pH while the sheep manure had an alkaline pH.

On the other hand, in table 3, it is seen that the bromatological composition of the substrates show that the sheep manure had the maximum values of lipids, fiber, ashes and proteins, while the organic wastes have the maximum quantities of carbohydrates.

Removal of COD



	1	2	3	4	5	6	7	8	9	10
DQO Inicial (g/L)	1.80	6.06	6.25	7.98	7.50	6.60	6.21	8.18	6.40	7.18
DQO Final Prom (g/L)	1.66	4.52	2.01	4.01	4.17	4.34	3.60	4.39	3.65	4.93

Figure 3. Chemical Oxygen Demand (COD) before and after anaerobic digestion.

The COD removal percentages can be seen more clearly in figure 3. The COD values before the digestion in each reactor were higher than that at the end of 43 days of digestion. These results are evidences of the effectiveness of the digestion, where the degradation of the organic waste is possible in an anaerobic digestion.

Biochemical methane potential CH_4/g COD ml

The values BMP of each treatment of co-digestion are shown in figure 4.

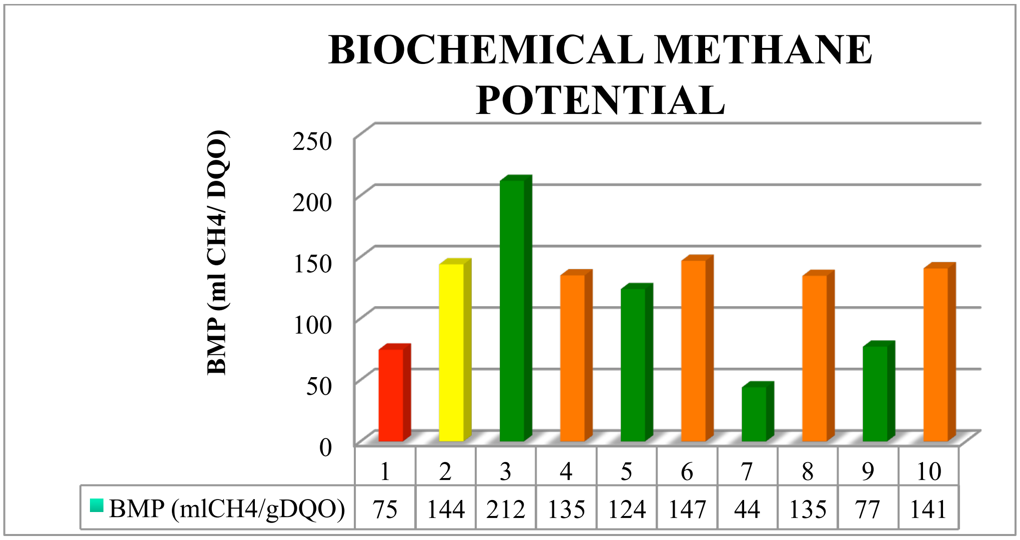


Figura 4. Biochemical methane potential in each bioreactor.

As we can see in figure 3, all the treatments show higher BMP levels performance with the digestion of MM with a value of 212 ml CH_4/gCOD. The lower values of BMP comes with treatments 7 and 9, that it is a co-digestion with 50% and 25% of MM respectively, which indicates that this balance could inhibit the reaction for the formation of methane. This also coincides with fact that these treatments have lower percentages of biodegradability, as it is shown in the table 4.

BIODEGRADABILITY	
MIXTURE OF ORGANIC WASTE AND SHEEP MANURE	EXP BMP/ THEORITICAL BMP
SM Control	41%
SM-MM 70:30	35%
SM-RIER 70:30	42%
SM-MM 50:50	21%
SM-RIER 50:50	38%
SM-MM 30:70	35%
SM-RIER 30:70	40%

Table 4. Percentage of biodegradability after the anaerobic co-digestion.

In the case of urban organic waste (RIER), there are no significant differences in the BMP for digestion, compared to co-digestion with sheep manure. These results show similar percentages of biodegradability. As a result, we can consider that the data displayed in the mixtures with urban waste (RIER) could be an advantage in the case of operation a biogas plant, given that the quantities of municipal solid waste generated in a city, vary daily in its composition.

CONCLUSIONS

The characterization of organic residues and sheep manure used in this study allowed us to establish the required quantity of each substrate for anaerobic digestion and anaerobic co-digestion.

It was evaluated the yield for the removal of COD and BMP in terms of ml of CH4/gCOD in tests of anaerobic co-digestion of sheep manure with organic waste of the Municipal Market (MM) and the urban organic solid waste, from Institute of Renewable Energy, UNAM (RIER) under mesophilic conditions in batch reactors. Different ratios of SM:RIER were treated (70:30, 50:50 and 30:70 %DQO) considering a range of 3-3.5 g of initial COD, adding activated sludge as inoculum of concentration between 1-1.5 g in STV/L and taking as positive controls 100% SM, 100% MM, and 100% RIER).

The kinetics of 43 days of anaerobic digestion indicated that the best yield for the removal of COD, and the maximum values of BMP given by MM. On the other hand, the addition of RIER to the SM favored the efficiency of organic matter removal of the SM control and it was obtained a removal of 46% with the ratio SM: RIER 50:50. However, it does not show a difference with the RIER control, which gave a yield of 49%.

Therefore, the addition of RIER to sheep manure is suggested to perform a co-digestion of these substrates for better yield of organic matter removal and BMP yield. However, the fact that there are no differences in the production of BMP between the treatments with the organic fraction of municipal solid waste, it could be an advantage for the industrial-scale treatment plants, since the composition of these residues is heterogeneous and vary every day.

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