CHEMICAL ENGINEERING TRANSACTIONS
VOL. 49, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Enrico Bardone, Marco Bravi, Tajalli Keshavarz

**ISBN** 978-88-95608-40-2; **ISSN** 2283-9216

DOI: 10.3303/CET1649065

# Anaerobic Co-digestion of Organic Residues from Different Productive Sectors in Colombia: Biomethanation Potential Assessment

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The residues enriched in putrescible materials and those with a high content of organic fraction produce large environmental impacts and other problems associated with the productive sector where they are generated. Colombia has a high biomass potential susceptible to be energetically valorized through biological processes achieving two functions: treatment and energy production. Anaerobic digestion is established as a technology with worldwide applications inside the circular biobased economy concept (cradle to cradle). Nevertheless, most of the studies related to technologies like anaerobic digestion have been concentrated on residues from industrialized countries. Considering the variability of residues composition depending on the level of development of a country, it is necessary to assess the biomethanation potential of biomass produced by different productive sectors in Colombia. In this study, a biomethanation potential assessment of organic residues (Organic Fraction of Municipal Solid Wastes, swine manure, cocoa husks and pods, residues from the bottled fruit drinks industry and rice stovers) from different productive sectors in Colombia was carried out. The biochemical methane potential (BMP) of each residue and its mixtures was carried out in a system which consisted in a battery of batch reactors (250 and 120 mL bottles) equipped with gasometers. To keep mesophilic conditions, an immersion thermostated bath was used. For all mixtures, an optimum C/N ratio of 20-30 was fixed based on the previous physicochemical characterization of the employed residues. The batch digestion process was evaluated until the total stoppage of gas production. The results indicate that the best mixture in terms of biogas production is the one containing cocoa, fruits and swine manure (C/N = 24), reporting a cumulative specific gas production around 497 mL $CH_4$/g VS. However, this result was lower than the sum of the ones reported by BMP for each individual substrate.

## 1. Introduction

Through the years the amount of solid wastes has increased due to economic development and the increase of population worldwide (Al-Zuahiri et al., 2015). Colombia has a potential of biomass to be exploited and valued through viable transfer knowledge projects using the various technologies available to industries. Most scientific studies of technologies such as anaerobic co-digestion have focused on raw materials from developed countries, so biomass from developing countries has been very little studied (Hernández et al., 2015; Thomsem et al., 2014). The anaerobic co-digestion is a microbial fermentation in absence of oxygen where the organic matter (of two or more substrates) is degraded during the phases of hydrolysis, acidogenesis, acetogenesis and methanogenesis to produce methane and carbon dioxide (Lorenzo Acosta & Obaya Abreu, 2005). It has several benefits like, minimizes the greenhouse gasses emission, allows the valorisation of solid wastes, contributes with low consumption of fossil fuels and increase the biogas yield compared to the individual digestion (Doublet

Please cite this article as: Cabeza I., Thomas M., Vasquez A., Acevedo P., Hernandez M., 2016, Anaerobic co-digestion of organic residues from different productive sectors in colombia: biomethanation potential assessment, Chemical Engineering Transactions, 49, 385-390
DOI: 10.3303/CET1649065

et al., 2013). The most common residues used as substrates during the anaerobic co-digestion process are municipal solid wastes, agricultural wastes, sewage sludge, and pig manures. (Facchin et al., 2013; Parra Orobio et al., 2015). Nevertheless, it is necessary to evaluate each type of residue according to the developing level of the country and the biomass species present in the region in order to obtain the real valorisation potential through this biological process based on its physic-chemical characteristics (Cabeza et al., 2013; Thomsem et al., 2014).

According to information provided by the Colombian Federation of Cocoa (FEDECACAO), cocoa planted area has risen by 35% in the past eight years, from 115.800 hectares in 2007 to 157.000 hectares in 2014, indicating that it is urgent to establish concrete solutions to the management and recovery of wastes from this sector, once it constitutes the main source of income for about 30,000 peasant families. Previous studies have shown that residues of the African cocoa variety maximizes methane production in anaerobic co-digestion and represents a viable option for countries with a panorama like Colombian (Hernández et al., 2015). Moreover, it is clear that the food industry generates a lot of waste that are going to atmosphere, water sources or directly to the sites for disposal of solid waste. Therefore, it is necessary to establish cleaner alternatives as anaerobic co-digestion, in order to recover wastes through biological processes and to make more efficient food industries in terms of energy (Restrepo-Gallego, 2006). Likewise, the Ministry of Agriculture and Rural Development of Colombia reported in 2006 that livestock sector has 76% (38.848.204 ha) of the total area for agricultural activities. Of this total, 10% is represented by hog farms. As estimates by the Mining and Energy Planning Unit of Colombia (UPME), the energy potential from the pig sector in the country is a total of 4.308,46 TJ / year. Municipal solid waste (MSW) is also an important source of residual biomass that could be recovered through co-digestion processes (Gómez et al., 2006). In Colombia, in 2002 there were generated daily 27,500 tons of solid waste, of which 40% (11,150 tons) were produced in the four major capital cities (Bogota, Medellin, Cali and Barranquilla) (Arrieta, 2008). In 2007, MSW production figures in Bogotá increased significantly to reach about 55,000 tonnes / year. Colombia has a real challenge related to solid residues, since 228 municipalities still have open dumps and 7 cities with a population of over 100.000 people are in environmental risk associated to the management of municipal solid wastes (SSPD, 2013). The composition and characteristics of this type of waste vary considerably and are depending on the standard of living of the population and level of development. The organic fraction of the waste generated by decomposing volatile organic compounds contribute to the greenhouse effect and cause discomfort and health problems in the population (Delgado-Rodríguez, 2011). However, their physico-chemical composition makes it a material with large energy value and therefore is necessary the study of their recovery by means such as anaerobic co-digestion, reducing the environmental and social impact that disposal in landfills. Finally, sludge from wastewater treatment systems have been previously studied in recovery processes by anaerobic co-digestion getting good rates biogas production and increasing overall process efficiency by decreasing the content of volatile solids (Fierro, 2014). For this reason, it is interesting to use this type of raw material as co-substrate and as inoculum in the process, also considering the high availability of this type of biomass in the country and the problems with water treatment companies to ensure proper management since stabilization is necessary if you want to be used as bio-fertilizer.

The biochemical methane potential (BMP) is a test commonly used to characterize raw materials in assays related to the optimization of the anaerobic digestion; It allows to find the type of substrate which has higher potential and it serves to determine methane production of different mixtures (Elbeshbishy et al., 2012). Nevertheless, this process has as disadvantage the length of time (30-90 days) necessary to be carried out (Doublet et al., 2013; Bekiaris et al., 2015). The probability and rate of degradation of each substrate depends of the concentration of microorganisms during the test, and its main parameters are the optimum C/N ratio, the temperature and the pH of the samples and the inoculums (Elbeshbishy et al., 2012).

This paper focuses on the evaluation of the production of methane through the process of anaerobic co-digestion using different substrates available in Colombia, with scarce information about methane yield (cocoa husks and pods, residues from the bottled fruit drinks industry and rice stovers), along with other common wastes (organic Fraction of Municipal Solid Wastes and swine manure). This evaluation was carried out applying the biochemical methane potential procedure for each type of residues and some mixtures based on the individual physico-chemical characterization. This work is a preliminary study which elucidates the valorisation potential of the residues evaluated through anaerobic co-digestion which allows generating opportunities to promote the distributed generation of energy in Colombia through renewable sources.

## 2. Material and methods

### 2.1 Inoculum

The inoculum was prepared employing swine manure from the Agriculture Research Center Marengo (C.A.M) of the Universidad Nacional de Colombia located in Mosquera – Cundinamarca. The initial solution was done with 200 g of swine manure in 1 L of distilled water. Once the mixture was homogenized, it was sieved to extract the coarse solids present in the solution and the organic matter not dissolved totally. The inoculum was prepared by duplicate using a reactor of 1000 mL with a work volume of 500 mL. Both reactors were kept in a thermo stated bath during 15 days without agitation at 36 ºC. Also each reactor was fed daily with a glucose solution (50 mL, 2 g/L).

### 2.2 Substrates

The substrates used in this work were: Organic Fraction of Municipal Solid Wastes, swine manure, cocoa husks and pods, residues from the bottled fruit drinks industry and rice stovers. All the residues were kept in a freezer at -4 ºC to avoid microbiological degradation before the assays.

***Residues from bottled fruit drinks industry (RBFDI)*** – These residues were simulated in the laboratory based on the references related to the residual streams of this sector. The materials used in this simulation were: papaya (shell), orange (seeds, peel and internal fibers), blackberry (pulp and seeds) and passion fruit (pulp and seeds). These were provided by Karpos S.A.S which is an alimentary factory that uses fruits and vegetables as raw materials. All the substrates were pretreated reducing their sizes through cutting and grinding processes until reach a size of particle of 0.5 mm approximately.

***Rice Stovers*** – It is a sub product of the rice harvest process. These residues are normally burned in open-pits. Actually, there are many efforts to valorize these substrates, some alternatives are their possible uses as organic fertilizer and as animal fodder (Federación Nacional de Arroceros, 2002). The materials were provided by the company Biocultivos S.A. located in Ibague – Colombia. All were pretreated with a size reduction process.

***Swine manure*** – The swine manure was obtained in the Agriculture Research Center Marengo (C.A.M) of the Universidad Nacional de Colombia located in Mosquera – Cundinamarca. The feeding of the animals was based on commercial concentrate.

***Cocoa Industry Residues (CIR)*** – The residues used were cocoa husks and pods and were obtained from a private farm in Santander – Colombia. The specie employed in this work comes from a crossing process of several species and is called trinitarium (Federación Nacional de Cacaoteros, 2013). It has different forms and sizes and it is the prevalent specie in Colombia. All the residues were pretreated using a size reduction process.

***Organic Fraction of Municipal Solid Wastes (OFMSW)*** - The residues were obtained from a typical home in Colombia. It is composed by 5 persons. Only organic fraction comprised of vegetables, fruits and processed foods was taking into account.

### 2.3 Biochemical methane potential assay

The BMP methodology used in this work is based on the principles described by Owen et al (1979) and Angelidaki et al (2009). The assays were carried out in 250 mL and 120 mL bottles, by duplicate, with a total work volume of 100 mL and 96 mL respectively. The Volatile Solids of the substrate and inoculum (S/X) ratio was 3. The inoculum used for the 250 mL bottles was 60 mL and for the 120 mL bottles was 29 mL, distilled water was used to complete the total work volume. All the bottles were sealed with rubber stoppers and silicone. The pH was adjusted in the range of 6.3 and 7.8 (Kondusamy & Kalamdhad, 2014). All the bottles were kept in a thermo stated bath at mesophilic conditions (36 ºC) during 20 days consecutively. Methane was determined by volume displacement and using a NaOH solution (pH>10) $CO_2$ trap (Cendales Ladino, 2011).

The BMP co-digestion assays were carried out considering 4 different mixtures with the swine manure as common factor due to its low C/N ratio. All the mixtures were based on the Volatile Solids (VS). The composition of each evaluated mixture is showed in Table 1. All the mixtures were prepared with a C/N of 24 and a VS ratio of 2.8 g VS/L taking into account the results of the determination of COD and TKN.

*Table 1: Mixture composition indicated each substrate used*

| Mixture | Substrates | | |
|---|---|---|---|
| | S1 | S2 | S3 |
| M1 | Swine manure | RBFDI | CIR |
| M2 | Swine manure | OFMSW | Rice stover |
| M3 | Swine manure | CIR | Rice stover |
| M4 | Swine manure | RBFDI | OFMSW |

### 2.4 Analytical methods

The properties evaluated were: Total Solids (TS) according to the procedure 2540B of Standard Methods (APHA), Volatile Solids (VS) according to the norm D3174 of the America Society for Testing and Materials (ASTM), Chemical Oxygen Demand (COD) following the D1252 – 06 of the America Society for Testing and Materials (ASTM), Total Kjeldahl Nitrogen (NTK) according to the D1426 – 15 of the America Society for Testing and Materials (ASTM) y Ammoniacal Nitrogen according to the T90 – 015 of the French Standard Methods (NF).

## 3. Results and discussion

### 3.1 Characterization of residues

In order to determine the amount of substrate to be used in single substrates and co-digestion mixtures experiments, the main physico-chemical characteristics of the residues studied were evaluated (Table 2). The ratio between volatile and total solids (VS/TS) could be used to indicate the organic fraction in these residues. All the ratios were greater than 0.7 which suggestt a good potential for biological digestion. Nevertheless, this characteristic should be treated with caution once the nitrogen content is an important parameter which affects the nutrient balance and the kinetic of the process. In terms of nitrogen content, the lowest concentration of rice stover could affect the balance and the requirements of microorganisms during anaerobic digestion. Meanwhile, residues from bottled fruit drinks industry and swine manure showed a NTK concentration that could make feasible the anaerobic process. Ammoniacal nitrogen was also analyzed, but the results for all the substrates have not showed a detectable concentration, avoiding inhibition by ammonia at the beginning of the tests.

*Table 2: Physico-chemical characterization (average SD in all cases was less than 5% over three samples)*

| Substrates | Parameters | | | | | |
|---|---|---|---|---|---|---|
| | TS (%)[b] | VS (%)[b] | COD [a] (g/L) | NTK (%)[a] | Moisture (%) | Ash Content (%)[b] |
| Residues from bottled fruit drinks industry (RBFDI) | 16.57 | 15.52 | 15.25 | 1.92 | 83.43 | 1.04 |
| Rice stover | 79.93 | 63.77 | 6.97 | 0.91 | 20.07 | 16.16 |
| Swine manure | 31.47 | 24.31 | 25.71 | 1.88 | 68.53 | 7.15 |
| Cocoa Industry Residues (CIR) | 15.94 | 14.96 | 10.46 | 0.99 | 84.06 | 0.98 |
| Organic Fraction of Municipal Solid Waste (OFMSW) | 22.76 | 21.24 | 13.73 | 1.56 | 77.24 | 1.51 |

[a] Samples over dry basis (d.b.) / [b] Samples over wet basis (w.b.)

### 3.2 Biological methane potential

According to every single substrate, the methane potential tests showed that wastes from cocoa industry residues had the highest methane yield of 382 mL $CH_4$/g VS, which is 2.9 times higher than the lowest value reached for swine manure. It was related to the low C/N ratio of manure which indicates a low availability as carbon source for microorganism's activity. In contrast, the high C/N value for CIR, RBFDI and rice stover showed the best BMP values achieved during the assays, with BMP between 192 and 382 mL $CH_4$/g VS. However, this high C/N ratio could cause a failure during the reactor operation due to the high volatile fatty acids (VFA) produced or related to the lack of macro and micronutrients (Moraes et al., 2015). The methane potential (Table 3) of these substrates, except cocoa industry residues, were lower than that reached for vinasse, sewage sludge, kitchen waste, palm oil mill effluent (POME) and empty fruit bunches (EFB) as pure substrates (Caporgno et al., 2015; Kim et al., 2013; Moraes et al., 2015; Ye et al., 2015).

*Tabla 3: Biological methane potential reached for every single substrate and the blend of some substrates.*

| Substrate | mL $CH_4$/g SV | C/N |
|---|---|---|
| Rice stover | 192±8.7 | 50.9 |
| CIR | 382±20.3 | 55 |
| Swine manure | 132±6.4 | 23.8 |
| OFMSW | 164±7.1 | 34.7 |
| RBFDI | 198±7.8 | 28.3 |

In order to improve the methane potential for the selected wastes, some tests were carried out with blends of these substrates. Figure 1 compare the BMP for each blend against the methane potential achieved for each single substrate. The methane potential tests showed that the first blend (M1) had the highest methane yield of 497 mL $CH_4$/g VS. It indicates an increase of 30% in methane production using cocoa industry residues, which is in the range of 13% to 44% reported for some authors when co-digestion are realized (Moraes et al., 2015; Ye et al., 2015). Meanwhile, the increase in the fourth blend (M4) was around 79% which suggested the best interaction between the substrates mixes. It could be explained due to the high sugar content of the fruits and the macro and micronutrients of swine manure and OFMSW which support the process even the buffer system. The others blend (M2 and M3) showed a lower methane potential compare to the single substrate. During the experiments, inhibition process was not detected, then the low yields were attributed to a common factor: rice stover presence. The co-digestion process shown the ability to reduce the deviation in biogas production for each blend compared to each single substrate. It was related to the use of swine manure as support substrate and the continuous availability of metabolites which kept the consortium activity.

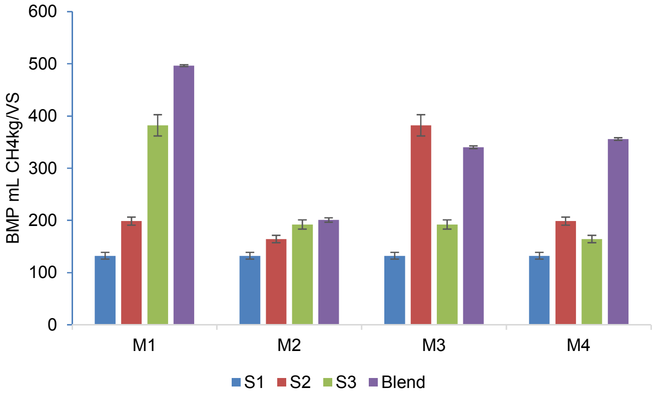


*Figure 1: Biological methane potential of blending substrates with a C/N ratio fixed to 24. M: Group of substrates used at each blend. S: Successive substrate used. M1: Swine manure, Fruits and Cocoa; M2: Swine manure, OFMSW and rice stover; M3: Swine manure, Cocoa and rice stover; M4: Swine manure, Fruits and OFMSW.*

## 4. Conclusions

The four substrates evaluated (swine manure, fruits, urban solid waste, rice stover and Cocoa) have the ability to be used for methane production. Cocoa showed a reliable potential of 382 mL $CH_4$/g VS which could be compared with other substrates studied. In addition, the results indicate that the best mixture in terms of biogas production is the one containing cocoa, fruits and swine manure (C/N = 24), reporting a cumulative specific gas production around 497 mL $CH_4$/g VS. In this condition, the co-digestion process showed a successful result increasing BMP at 30%. Nevertheless, the highest increase of 79% was reached by the mixture of Swine manure, Fruits and USW, but just the BMP of 356 mL $CH_4$/g VS. These results allow to elucidate the valorisation potential of some local wastes, with a great environmental impact in the region, through biological processes of anaerobic co-digestion. The biogas potential found for substrates and the mixtures ratio is the first step in order to create empirical models that guarantee the optimization of the process from the technical, environmental and economic point of view.

### Acknowledgments

The authors acknowledge financial support from Colciencias (Administrative Department of Science, Technology and Innovation of Colombia). Project number FP 279-2015. Special thanks to the reviewers of CET for their valuable comments and corrections.

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