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Conference Paper · October 2020

DOI: 10.1109/IREC48820.2020.9310433

6 authors, including:

Mouftahi Mawaheb

Pietro Bartocci
Università degli Studi di Perugia

Federica Liberti
Università degli Studi di Perugia

Bio-methanisation potential (BMP) test for organic waste available in the south region of Tunisia

Mawaheb Mouftahi [1]

Nawel Tlili [2]

Nejib Hidouri[1]

Pietro Bartocci [3]

Federica Liberti[3]

Francesco Fantozzi [3]

[1] Gabès university. National School of Engineers.
Applied Thermodynamics Research Laboratory.
Omar Ibn El Khattab Street. 6029 Gabès. Tunisia.

[2] Gafsa University. Materials. Environment and Energy Research Unit (UR14ES26).
University Campus - Sidi Ahmed Zarroug. 2112 Gafsa. Tunisia.

[3] University of Perugia. Department of Engineering.
Via G. Duranti 67. 06125 Perugia. Italy.

***Abstract*— Driving into renewable energy production from organic resources and wastes becomes the most effective solution to cover the energy demand and to reduce the environment issues. Recent studies report that anaerobic digestion, especially the co-digestion, is an efficient alternative technology that combines bio-energy production with sustainable waste management. Tunisia is one of the countries which suffer from energy demand problems and environment issues. Thus, Tunisian government turns on the development of renewable energy. Therefore, this study focuses on the evaluation of biogas and bio-methane yield from the co-digestion of three available and abundant bio-wastes in the south regions of Tunisia. In this context, bio-methanisation potential test (BMP) was carried out to this evaluation. As a result, the biogas and bio-methane cumulative were respectively equal to 0.263 Nm3 biogas/ Kg VS, 0.166 Nm^3_{CH4}/Kg VS for bottle 1 and 0.134 Nm^3_{biogas}/ Kg VS, 0.069 Nm^3_{CH4}/Kg VS for the blank. This test gave volatile solids reduction equal to 98.99% and 96.81 %.**

Keywords—south Tunisian biomass; BMP; Biogas; Bio-methane; VS reduction

I. INTRODUCTION

The continued use of fossil fuels and the environmental effects of greenhouse gases (GHGs) have launched research efforts on the production of alternative fuels from biological resources. The amount of GHG emissions into the atmosphere is increasing, with carbon dioxide (CO2) being the main contributor. Besides, global energy demand is growing rapidly, with around 88% of the energy currently produced being based on fossil fuels [1]. Among various renewable technologies, anaerobic digestion technology is a commercially well-tested technology and is widely used for treating biomass. Currently, this technology is a more attractive method of renewable energy due to reduced technological cost and good process efficiencies. Different varieties of substrates such as animal waste, wastewater, industrial waste, agricultural residues, municipal solid waste energy crops, and water based resource like algae are extensively used for the anaerobic technology [2]. Anaerobic digestion is a biochemical process by which complexes of bacteria degrade the complexity of organic matter under anaerobic conditions. It is an environmentally friendly process and one of the most effective methods for converting biomass to CH4. Anaerobic digestion is a complex microbial process that occurs naturally in oxygen-free environments. It is a four-step process including hydrolysis, acidogenesis, acetogenesis, and methanogenesis [3]. Biogas generated by the digestion of biomass has the potential to meet energy needs while offering multiple environmental benefits [4]. Biogas is the final product of the anaerobic digestion, which consists of methane, carbon dioxide, and traces of other compounds, such as NH3, siloxanes, H_2, N_2, and O_2. Biogas can be used directly as fuel, in the combined heat and power gas engines, or it can be upgraded to bio-methane. The effluent remaining after anaerobic digestion is a nutrient-rich substrate (digestate) and it can be used as fertilizer for agronomic applications [5].

Anaerobic co-digestion can be considered as the instantaneous digestion of two or more substrate and co-substrate mixtures that become more useful than the mono-digestion. The primary concern for the anaerobic co-fermentation process is improving biogas and methane generation yields. Besides, it can improve process stabilization, nutrient balance, and the synergistic effects of microorganisms, and can reduce greenhouse gas emissions and processing costs. Moreover, the co-digestion gives the value to valorize different wastes at the same time [6].

Tunisia is one of many countries worldwide with a growing economy and increasing conventional energy consumption. As a result, it needs to balance economic development with environmental concerns. Tunisia, and particularly the south region, has a large amount of organic waste such as municipal solid waste (MSW), chicken manure (CM), and olive mill wastewater (OMWW), which are thrown at the end of the city or buried in large pits causing undesirable environmental and economic problems. In this context, the present project had been experimented to evaluate the energy potentiality and anaerobic process efficiency for the most available and relevant organic wastes in the southern regions of Tunisian by caring out the bio-methane potential

978-1-7281-5572-2/20/$31.00 ©2020 IEEE

test of this especial co-digestion mixture, which can be a good initiative for applications on a larger scale concerning the municipalities and the industrial facilities to supply the energy needs and to reduce both energy problems and environment issues.

II. Materials and Methods

A. Organic materials

The abundant quantity of the organic fraction of municipal solid waste, chicken dropping, and the olive mill wastewater in the south region is the most important factor that gives the value to valorize these bio-wastes. A sorting pretreatment phase of recyclable materials mainly paper and cardboard, removal of non-organic waste such as metals, and grinding the substrates are essential before the anaerobic digestion test. The biodegradation of recalcitrant biomass needs suitable inoculums to accelerate this operation. As a condition, the source of inoculums is essential because the inoculums must contain a high number of active microbe communities that can convert the organic substrates into biogas [7]. In recent work, the inoculums were the primary digestate from biogas station situated in the municipality region of Perugia (Italy) [5]. The used inoculums were composed of different organic substrates as following; 62.28 % maize, sorghum, and triticale silage, 16.26% humid pitted pomace, and 21.55 % pig wastewater. For the optimization of the anaerobic digestion process, the selection of inoculums source and the substrates to inoculums (S/I) ratio are the important operational parameters for the assessment of anaerobic biodegradability of wastes [8]. In their study [9] showed that the methane yield reaches its maximum at (S/I) values between 0.6 and 0.9, and inhibitions occur when the ratio exceeds 1. In this study, we will keep to lunch the anaerobic digestion with an optimal (S/I) ratio.

B. Anaerobic digestion process

Anaerobic digestion is a complex multistep process in terms of chemistry and microbiology. Organic material is degraded to basic constituents, finally to biogas, a mixture of methane and carbon dioxide, and other gases under the absence of an electron acceptor such as oxygen. To achieve this pathway, the presence of very different and closely dependent microbial populations is required [10]. The basic metabolic pathway of anaerobic digestion is shown in Fig. 1. As described in the work of [5].

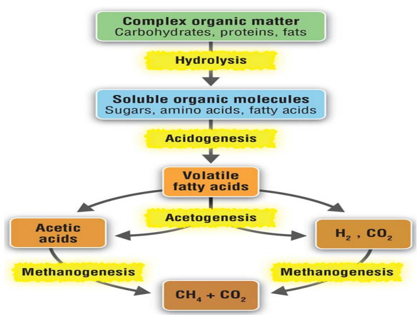

Fig.1. Different steps of anaerobic digestion process

C. Bio-methanisation potential (BMP) test procedure and setup

The test was carried out using particular vessels, with a global capacity of about 1 liter realized in Boro-silicate glass. One bottle was filled up to 25% of its volume with different mixtures of kitchen waste, chicken manure, olive mill wastewater, and the inoculums respectively by mass percent 4.4%, 2.2%, 4.4%, and 89% and in the total mass equal to 250 g, another one was filled only by the inoculums with, that is equal to 89% from the mix mass, it is the blank bottle. Then pressure sensor UNIK 5000 GE Measurement & Control is applied and the vessels were sealed and immersed in a thermostatic bath in mesophilic conditions approximately 35 ±0. 5°C. The mesophilic condition between 30 and 40 ° C is the most favorable for the fermentation [11]. The two bottles are bioreactors. They were used to follow the pressure evolution of the anaerobic digestion. Mixing has an important influence on the anaerobic digestion, shaking one time a day (for 1 minute) during the test period is essential [12]. We kept lunching the anaerobic digestion with a pH value equal to 7.

The following fig.2 shows the experimental setup and the technology process.

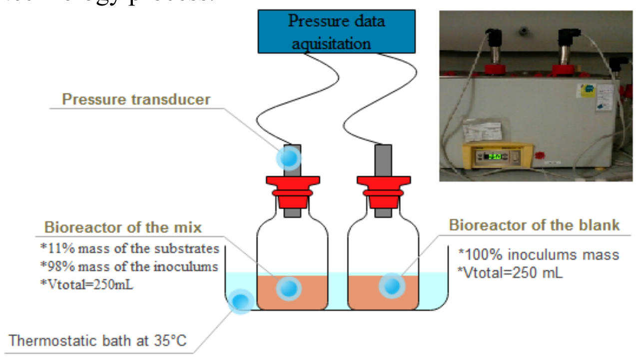

Fig.2 . Experimental setup

III. Analytic Methods

Each sample was subjected to proximate analysis to determine the physicochemical characterizations. In this work, we are interested to obtain essentially humidity (H) [%], total solid (TS) [%], and volatile solids (VS) [%] matter according to CEN/TS 14774, CEN/TS 14775, and CEN/TS 15148, using a thermo-gravimetric analyzer (TGA-701, LECO Co., USA). The pH measurements were carried out by a portable pH Meter HI9124 with a resolution of 0.01 which uses a double junction pH electrode. Biogas production is evaluated by measuring the pressure variations through UNIK 5000 Pressure Sensors (accuracy to ±0,04% Full Scale), connected to a NANODAC data acquisition system. Biogas samples are analyzed through an Agilent 490 Micro gas-chromatograph. The analysis tests were carried on the Analysis Lab of the Biomass Research Centre “Centro di Ricerca sulle Biomasse” (University of Perugia Italy) as described in the previous works [13], [14].

IV. Mathematical Equations

In this work, the following equations were used:

$$C_{physic\text{-}chemical}(\%) = \frac{\sum_{i=1}^{4} \chi_i \times m_i}{m_t} \quad (1)$$

$$(VS)_{mass} = \sum_{i=1}^{N} \chi_i \times m_i \quad (2)$$

Where: $C_{physic\text{-}chemical}(\%)$: one of the physic-chemical characterizations such as (H), (TS), or (VS) in percent [%], i: the corresponding material (CM, MSW, OMWW, or inoculums), : χ_i the percent of the corresponding physic-chemical characterization of material (i) , m_i: the mass of the material (i), m_t: mixture mass was equal to 250g , $(VS)_{mass}$: the corresponding (VS) mass of the substrates which is composed of (CM, MSW, OMWW) or only the inoculums, N: in the case of (VS) mass of the substrates N=3, and in the case of only the inoculums N=1.

$$Y_{biogas} = 10^{-3} \times [(\frac{P_{mesured} \times 0.986 \times T_{NT}}{P_{NP} \times T_r}) \times V_r] / [Kg(VS)] \quad (3)$$

Where: Y_{biogas}= the daily of the biogas production, expressed in (Nm^3/Kg VS), $P_{measured}$: headspace pressure before the gas sampling (atm),T_r and V_r: temperature (K) and headspace volume (L) of the reactor,T_{NP} and P_{NP}: Normal temperature and pressure, 273,15K and 1 atm respectively, 0.986: to convert pressure from bar to atm (1bar= 0.986 atm), [kg (VS)]: the mass of the used (VS) in Kg in each bio-reactor.

$$Q = \sum_{n=1}^{n} q_n \quad (4)$$

Where, Q: the cumulative biogas/bio-methane production (Nm^3/kg VS), q_n: the daily biogas/bio-methane production (Nm^3/kg VS), n: the corresponding day during AD.

$$(VS)_n = \frac{Y_{biogas} \times [Kg(VS)]}{Q} \quad (5)$$

Where: $(VS)_n$: daily mass reduction of the volatile solid during (n) days in (Kg VS), Y_{biogas} × [Kg (VS)]: daily biogas production from the used materials, Q: the cumulative biogas production (Nm^3/kg VS), n: the days during AD.

The percent reduction of the volatile solid is calculated as following:

$$(VS)_{reduction}(\%) = (\frac{(VS)_{initial} - (VS)_{final}}{(VS)_{initial}}) \times 100 \quad (6)$$

$$(VS)_{final} = (VS)_{initial} - \sum_{n=1}^{n} (VS)_n \quad (7)$$

Where: VS $_{reduction}$(%): the percent reduction of the initial volatile solid mass of the used materials in (%), (VS) $_{initial}$: the mass of the volatile solid of the materials in each bio-reactor, $(VS)_n$: (VS) mass reduction in n day, n: the corresponding day during AD.

V. Results and Discussions

A. *Physic-chemical characterizations*

To increase biogas production, the physic-chemical parameters are essential to be analyzed according to [15]. The substrate and inoculums characterizations are summarized in table.I. Humidity has a great influence on the action of bacteria. Water must be added, if necessary, to the raw material to generate a mud that is neither too thick nor too thin. If a material is too diluted, solid particles can settle in the digester and not degrade properly. If the suspension is too thick, it can be difficult to stir and can prevent gas from flowing to the top of the digester. Different systems can handle different levels of suspension density, typically in the range of 10-25% total solids [16]. For the estimation of the water content of a load, the TS or the dry matter were determined. The percentage of TS allows classification of the type of digestion process according to [4]. More than 87% of moisture in the digestion capacity is provided by single-phase digesters, which can use wet or dry technologies [17]. In this work, the humidity is equal to 86.06 that showed the anaerobic digestion test is a one-single dry process. To determine the amount of organic matter in a sample, the (VS) (%) or organic dry matter were determined [15]. The characterizations of the mixture are calculated according to the Eq. (1).

Table I. Physic-chemical characterizations

Sample	(H) [%]	(TS)[%]	(VS)[%]	Mass (g)
MSW	50.3	49.7	44.49	11
OMWW	65.33	34.67	25.92	11
CW	50	50	29	5,5
inoculums	89.75	10.25	7.14	222.5
Mixture	86.06	13.93	10.09	250

In the previous studies, it has been observed that the substrate to the inoculums ratio (S/I) also plays a significant parameter to specify the appropriate inoculums volume to provide the required amount of microorganism for the anaerobic reaction to startup. The volume of inoculums used will influence the amount of methane produced [18]. The compositions fractions in the digester with the different weights, as it is mentioned in the bio-methanisation potential (BMP) test procedure part give an outline about the different ratios of the (S/I). The (SV) mass of substrates and inoculums were respectively equal to 9.34g and 15.88 g using Eq (2). Thus, the used mass percents tend to give (S/I) ratio value equal to 0.59 using the ratio between (VS) mass of the substrates and the inoculums. The value was near to 0.6 as mentioned in the work of [9] this value was optimal for the fermentation.

B. Daily biogas and bio-methane production

The measurement of the production was carried out under controlled conditions, fixed temperature (35°C) according to Eq. (3). The anaerobic digestion test lasted 40 days. Daily production curves of biogas and bio-methane of the tow bioreactors are showed respectively in fig.3 and fig.4. The daily bio-methane volume calculation was done according to the percent of the bio-methane in the total volume of the biogas using the gas-chromatograph for the percent compositions detection. The daily curves productions present three important phases, the first one from is the first 9 days, this period was characterized by the absence of the fluctuation in the biogas and bio-methane production. This period highlights the startup of anaerobic digestion; this means the beginning of organic matter degradation by microbial organisms in the bioreactor to form biogas. The lack of fluctuation explains the higher adaptation of the microorganisms in the fermentation medium [19]. The second phase lasts from the 10 th days to nearly 30 th days. In this period, clear fluctuation produced that explains inhibitor products accrued [20]. The cumulative biogas and bio-methane were respectively 0.263 Nm3 biogas/ Kg VS, 0.166 Nm3CH4/Kg VS, and 0.134 Nm3 biogas/ Kg VS, 0.069 Nm3CH4/Kg VS for the bottle 1 and the blank respectively using Eq. (4). According to these cumulative volumes, the bio-methane percent in these two bioreactors respectively were 63.11% and 51.49%, showing that the bio-methane is the main composition in this bio-production.

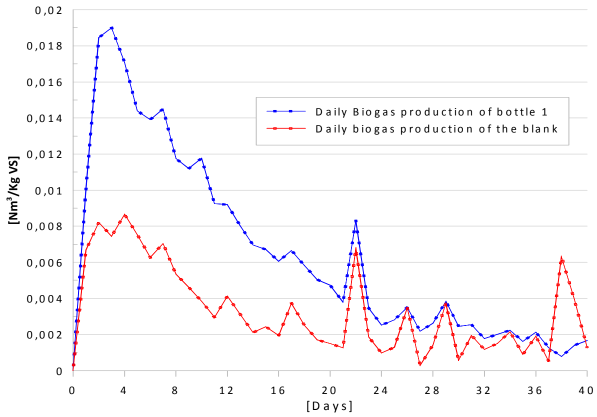

Fig.3. Daily biogas production of the two bio-reactors

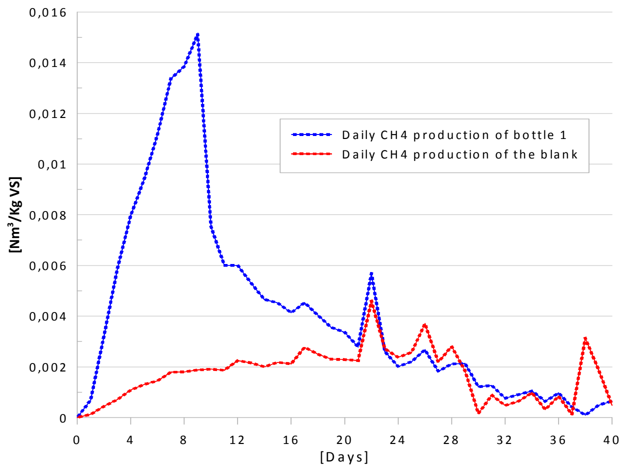

Fig.4. Daily CH_4 production of the two bio-reactors

C. Volatile solids reduction

When considering the biogas process for a specific application, the characteristics of the substrate/waste are naturally of prime interest. Waste and wastewater have a complex composition. The most common single measure used to describe the concentration of waste is the volatile solids (VS) content. The (VS) content describes the content of organic material in the wastes and is defined as the amount of matter of a dried sample [21]. To evaluate the performance of the fermentation process during the degradation of the bio-wastes and the transformation into biogas, knowing the reduction of (VS) concentration is interesting parameters[22].

The curve in the following fig.5 shows the reduction of the volatile solid mass for the period of anaerobic digestion test until the steady-state becomes practically null, using a mathematical relation between the biogas yield and the cumulative volume as illustrated in Eq. (5). In the present study, the (VS) reduction percent were respectively equal to 98.99% and 96.81 during the anaerobic period test for bottle 1 and the blank according to Eq. (6). Retention time or residence time, in the AD systems is the amount of time a feedstock resides in an anaerobic digester that affects anaerobic degradation. 40 days in this work, it is the time required for the organic material residing in a digester to decompose the (VS) in influent to give these higher percent of efficiency. The longer is the retention period; the better is the degradation of the organic matter. The residence time is designed by the microbial communities present in the digester that operate at different rates and at different times [23].

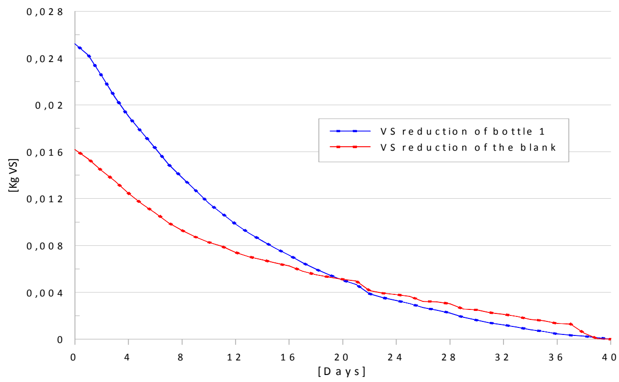

Fig.5. (VS) reduction of the bio-reactors during the biogas production

D. Global report

In order to fix the ideas, the fig.6 illustrates a general description about the process of the anaerobic digestion of the mix organic waste used. This flow sheet is very useful to clarify the input and the output of the mix and the blank.

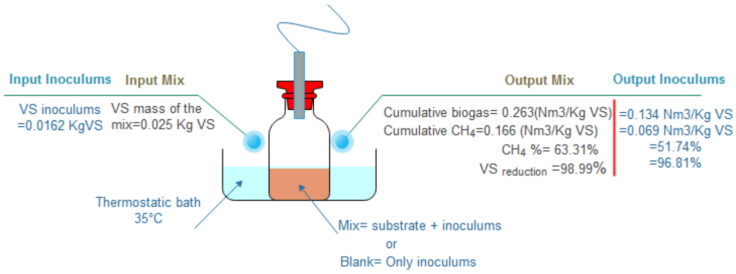

Fig.6. General description of the process

VI. Conclusion

The objective of this study is to assess the potential of biogas and bio-methane produced from biomasses available in the south of Tunisia. In this case, the abundance of olive mill wastewater, municipal solid waste, and chicken manure lead us to think of adding value to these last 3 biomasses. This project allows us to use an abundant resource in the south, avoid pollution problems, and essentially provide a significant potential for renewable energy. The importance of the co-digestion of the above waste is also manifested in the enrichment of research since there is insufficient research related to the theme of the recovery of this waste. As a recommendation to this work, it is important to determine the net production of the substrates and the real yields of the biogas, bio-methane production, and the net (VS) reduction during the anaerobic digestion by substring the inoculums volume production amid the mixture.

Acknowledgement

I would like to express my deep gratitude to Prof. H. Nejib and Prof. T. Nawel, my research supervisors, for their patient guidance, enthusiastic encouragement and useful critiques of this research work. I would also like to thank Prof. F. Fantozzi, to accept me in his research laboratory “Centro di Ricerca sulle Biomasse”, Perugia. Italy. I would like to express my very great appreciation to prof. B. Pietro for his valuable and constructive suggestions during the planning and development of this research work. I would also like to extend my thanks to Dr. L. Federica to help me in the analysis part.

All the authors would like to thank the biogas station situated in Umbria region.

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