Evaluation of gas production in a industrial anaerobic digester by means of Biochemical Methane Potential of Organic Municipal Solid Waste Components

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Abstract:

The Biochemical Methane Potential (BMP) of several components of the Organic Fraction of the Municipal Solid Waste (OFMSW) were tested in order to assess the possibility to obtain a good estimate of the biogas production of a real scale anaerobic digestion plant. In particular, five different fractions and a mixed food waste sample were tested with batch anaerobic digesters at 37°C and both the BMP after 21 days (BMP21) and final BMP (BMPf) were measured. Regarding the mixed food waste substrate it was found an average BMP21 of about 405 NL/kgVS and a BMPf of 484 NL/kgVS with an average methane content of 57%. From the experimental results, some industrial potential biogas production were defined to compare them with data from real anaerobic digestion plants. In particular two different plants were considered: one located in a rural area that treats the source selected OFMSW from a public collection point, another located in a city area with a curbside collection system. Furthermore, studying the BMP of the pre-treatment reject of these plants, it was possible to study the pre-treatment efficiency and the difference performance of the two real plants.

Keywords:

Anaerobic Digestion, Biochemical Methane Potential, Biogas, Organic Fraction Municipal Solid Waste.

1. Introduction

In 2009, more than 10 million tons of waste, corresponding at the 33,6% of the whole amount of municipal solid waste (MSW) produced in Italy, were collected as source separated fractions. About the 35% of these fractions were organic fraction from kitchen and yard and garden waste and, since 2005, a constant increasing of 11% every year have been recorded. Moreover ISPRA [1] shows that most of them were treated in composting plants (about 281 facilities were registered in the 2009) and about 540'000 t where instead stabilized in anaerobic digestion plants, in particular 18 plants of which 15 working.

New strategies in MSW management, i.e., source-separate collection of the OFMSW and the need to reduce the biodegradable-MSW allocated in landfill, have favoured the development of composting and anaerobic digestion as useful biotechnologies for transforming organic waste into suitable agricultural products [2]. Moreover, given that the amount of OFMSW is still increasing and the attention to the environmental impacts is becoming all the time more important, the possibility to recover not only compost form waste but also energy could enhance the anaerobic digestion of OFMSW as way to provide a clean fuel from renewable energy [3]. In this way the quality of the OFMSW in terms of potential methane production becomes important in order to assess the biogas production expectation from the anaerobic treatment.

In the last years, several researches have been carried out for the analysis of biomethane potential of several waste substrates. In particular, most of these utilize BMP analysis as a possible way to characterize the biodegradability of the organic matter in order to assess its stability and the waste treatments efficiencies such as composting or anaerobic digestion. Others are instead interested in determining waste BMP as relevant in the context of treatment by anaerobic digestion and useful to determine the amount of organic carbon that can be anaerobic converted to methane. This research focus on this last purpose with the aim to understand how, by measuring the BMP of the main component of the OFMSW is possible to estimate the potential biogas production of real digestion plant. Moreover, to obtain more realistic results, this research focuses on how the pre-treatments and the operating environment could affect the biogas production of real plants.

2. Materials and methods

To study the BMP of the source-selected organic fraction, essentially kitchen and garden waste, several substrates were tested; in particular: proteins from meat and dairy products, carbohydrates from bread and pasta, fruit and vegetable, dirty paper from kitchen and other organic materials from yard and garden waste. Moreover, to assess the efficiency of a typical anaerobic digestion plant, it was also necessary to measure the BMP of the fractions rejected by the pre-treatment. In particular it has been possible to test the light fraction and the small heavy removed from the OFMSW by a specific treatment in two real industrial anaerobic digestion plant with different location: a rural and a urban area.

To estimate the biogas potential production of each fraction, the BMP analysis were carried out in duplicate and both the BMP21(biogas produced at 21 days) and the BMPf (when no significant biogas production is detected) were measured. For analysis a modified method of Ponsa et al. [4] was used and in the following, according with Angelidaki, Alves and Bolzonella et al. [5], the materials and the method used will be described.

2.1. Inoculum and substrates tested

Active inoculum from a mesophilic anaerobic digestion plant, that primarily treats organic fraction from MWS, was used. In order to deplete the residual biodegradable organic material present [5], the inoculum was pre-incubated for three day in a water bath at 37°C. Total Solid (TS) and Volatile Total Solid (VS) contents were about 3,9% on wet weight basis (w/w) and 64,1% on TS basis, respectively.

Table 1. Characterization of the substrates used

Substrate	*Experimental ID*	*TS, %FM*	*VS, %TS*
Proteins	Proteins	33,1±0,24	89,9±0,01
Carbohydrates	Carbohydrates	94,5±0,04	97,5±0,01
Fruit and vegetables	Fruit and Veget	14,0±0,05	98,1±0,06
Leafs	Yard and Garden waste	6,5±0,61	81,8±1,48
Cellulose	Dirty paper	40,3±0,02	90,4±0,04

The source selected OFMSW from curbside collection was used for the substrates tested in the batch assay. For each fractions water content and VS were measured in triplicate, in Table 1 only the mean value are shown.

Furthermore, a mixing of those fractions (Mixed Food Waste – MFW) was employed for the tests too; its composition is shown in Table 2. TS and VS contents, as the sum of each fractions, were about 42,4±0,38% (w/w) and 93,3±0,01% on TS basis respectively.

Table 2. Mixed food waste composition

Fraction	*Weight (g)*	*Percentage %(w/w)*
Fruit and vegetable	8	26,7
Proteins	8	26,7
Carbohydrates	8	26,7
Leafs	3	10
Cellulose	3	10

2.2. Set-up of measurement

The BMP was determined using 1L stainless steel bottles, incubated in a water bath at 37,5°C, tightly closed by special cap provided with a ball valve to enable the gas sampling. To ensure anaerobic conditions, the bottles were flushed with inert gas. All the equipment, 2 bar proof pressure, was specifically design and developed.

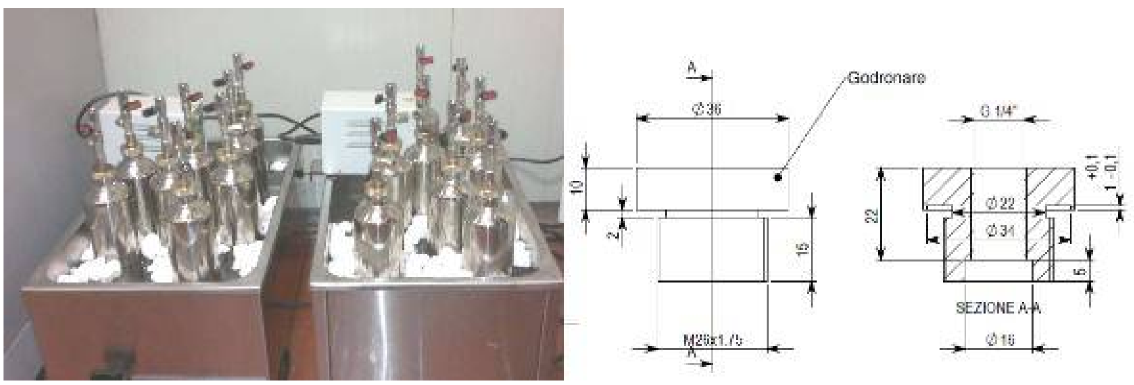

Fig 1. Batches and cap used

With the fractions described above, six sample and twelve batch reactors (the test was performed in duplicate) were prepared. Each reactor was loaded with different quantity of substrate, depending on the characteristics of the materials, to achieve a concentration of substrate in each batch of about 2gVS/100 mL solution, given that this concentration is a compromise of, one hand, the need to use a large sample to have good representativity and to get a high easy-to-measure gas production, and, on the other hand, to avoid too large and impractical volumes of reactors and gas production and keep the solution dilute to avoid inhibition from accumulation of volatile fatty acid (VFA) and ammonia [6].

Moreover, in every case, the inoculum to sample ratio was kept under 10:1 weight ratio, according with Ponsa et al. [4] for fresh feed-in substrate, and because it was demonstrated that the amount of inoculums should be enough to prevent the accumulation of volatile fatty acids and acid conditions[5].

To determine the background methane production, a blank assay with the only inoculum was done in duplicate.

According with the authors [7], biogas production was estimated by measuring the pressure in the head space of each reactor and then converting to volume by application of the ideal gas law.

Pressure was measured using a membrane pressure gauge (Model HD2304.0, Delta Ohm S.r.L., Italy). The values of pressure measured were converted into biogas volume as:

$$V_{biogas} = \frac{P_{measured} \cdot T_{NTP}}{P_{NTP} \cdot T_r} \cdot V_r$$

where:

V_{biogas}, volume of daily biogas production, expressed in Normal litre (NL);

$P_{measured}$, headspace pressure before the gas sampling (atm);

T_r and V_r, temperature (K) and volume (L) of the reactor;

T_{NTP} and P_{NTP}, Normal temperature and pressure, 273,15K and 1 atm respectively.

The headspace volume, calculated as the difference between the total volume of the batch and the volume occupied by the sample considering a sample density of 1g/mL, was about 600ml for each bottle.

The gas produced was routinely analyzed using an IR gas analyzer (ECOPROBE 5 - RS Dynamics). After every measurement the bottles were shaken to guarantee homogeneous conditions in the assay vessels [5].

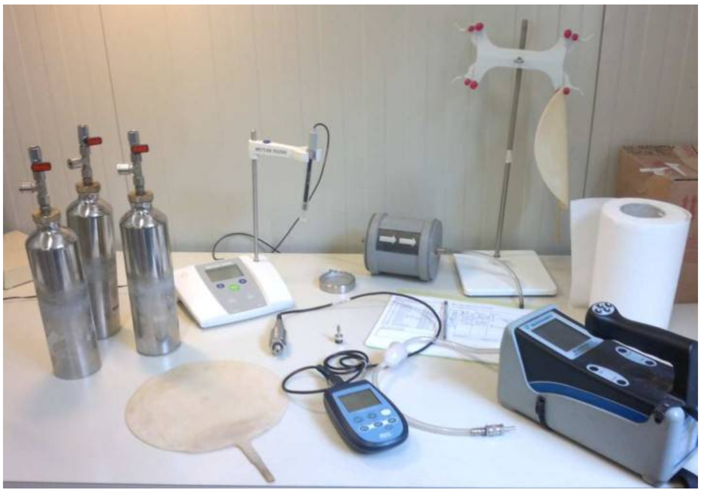

Fig 2. Laboratory equipments

The BMP was determined as the cumulate biogas production, calculated as the sum of the daily volumes, divided by the TS and the VS present in each batch. The results, reported in the Normal Temperature and Pressure (NTP), were obtained after 21 and about 90 days. After this period, in fact, the quantity of biogas produced by every sample was found to be lower than the blank production and no significant biogas volumes can be considered.

3. Results and Discussions

3.1. BMP assay

The results obtained for the biochemical methane potential at 21 days are shown in Table 3. In particular the quantity of biogas produced is referred to the TS and the VS and, in order to consider the inoculum biogas production, a percentage error is also shown. It was calculated as the ratio between the quantity of biogas produced by the inoculum and the total biogas produced from each fraction.

Table 3. BMP21

Experimental ID	NL/kgTS	NL/kgVS	Error, %
MFW (a)	413	542	14
MFW (b)	396	520	14
Proteins	386	528	14
Carbohydrates	91	109	67
Fruit and Veget	250	353	21
Yard and Garden waste	115	175	42
Dirty paper	315	422	17
Inoculum	47	74	-

Preliminary experiments on similar waste showed that 90 days of incubation at 35°C, after the lag period, was sufficient to insure the total gas production expression [8], therefore the values of BMP measured after 93 days has been considered as the final biogas produced by each substrate. The results obtained, deducted the inoculum yield, seem to be comparable to that obtained in other similar studies [9] and [10].

Table 4. BMPf

Experimental ID	NL/kgTS	NL/kgVS	Error, %
MFW (a)	501	657	31
MFW (b)	466	611	33
Proteins	452	617	33
Carbohydrates	101	120	168
Fruit and Veget	327	462	44
Yard and Garden waste	205	312	65
Dirty paper	377	504	40
Inoculum	130	203	-

The highest BMP value was obtained for the MFW, while, observing the calculated errors, it is clear that for charbohydrates some problem of acidification occurred.

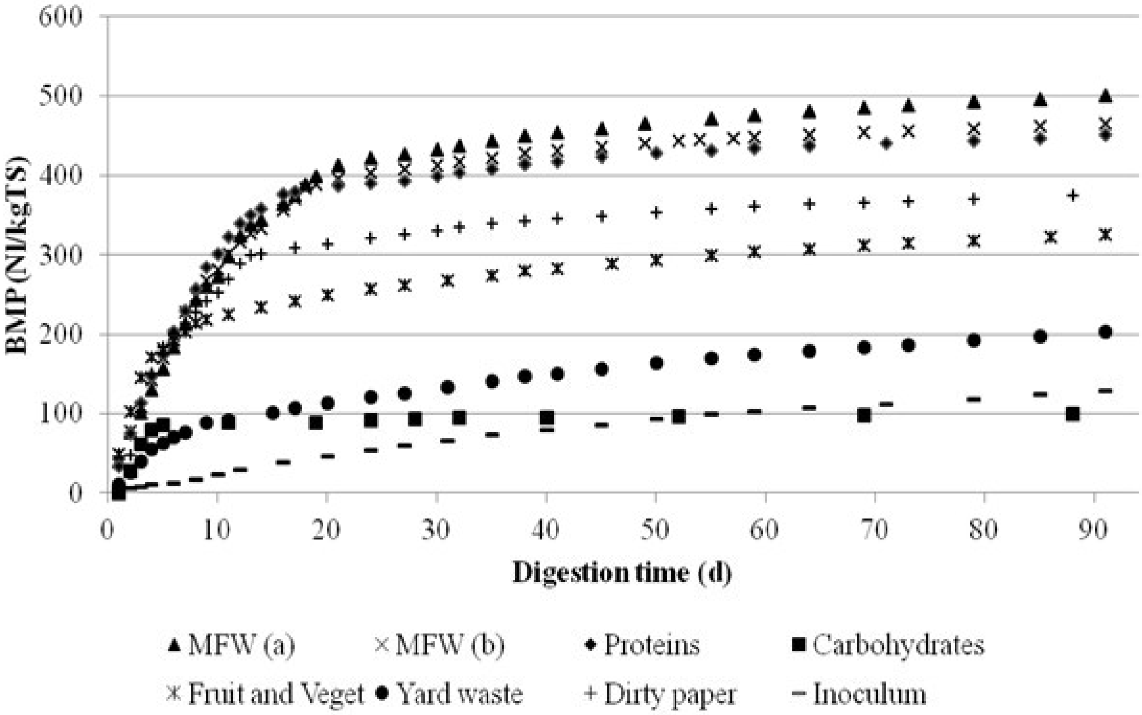

Fig. 3: Cumulative Biochemical methane production of the tested samples

This can be also noticed in the temporal plot of the average cumulative biochemical methane yields (Fig. 3): for the soon after few days, no significant methane production was detected.

With reference to Fig. 4, the correlation between the BMP21 and the BMPf has been studied [4]. As results from the chart, the biogas obtained at 21 days corresponds to the 89% of ultimate potential methane. In fact, as supported by the comparison between the cumulative and the daily MFW average BMP, the main part of the biogas totally produced was released during the first 20 days (Fig. 5).

Focusing on the MFW results, the peak value of daily biogas production was about 51 NL/d*kg VS, while the cumulative biogas were 542 and 520 NL/kgVS for the MFW (a) and (b) sample.

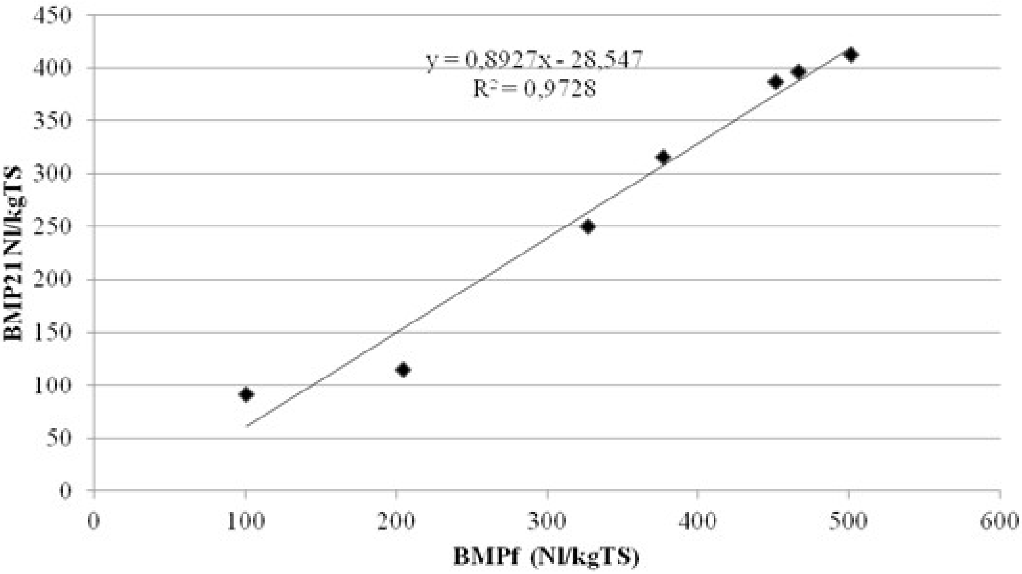

Fig. 4: BMP21 and BMPf correlation

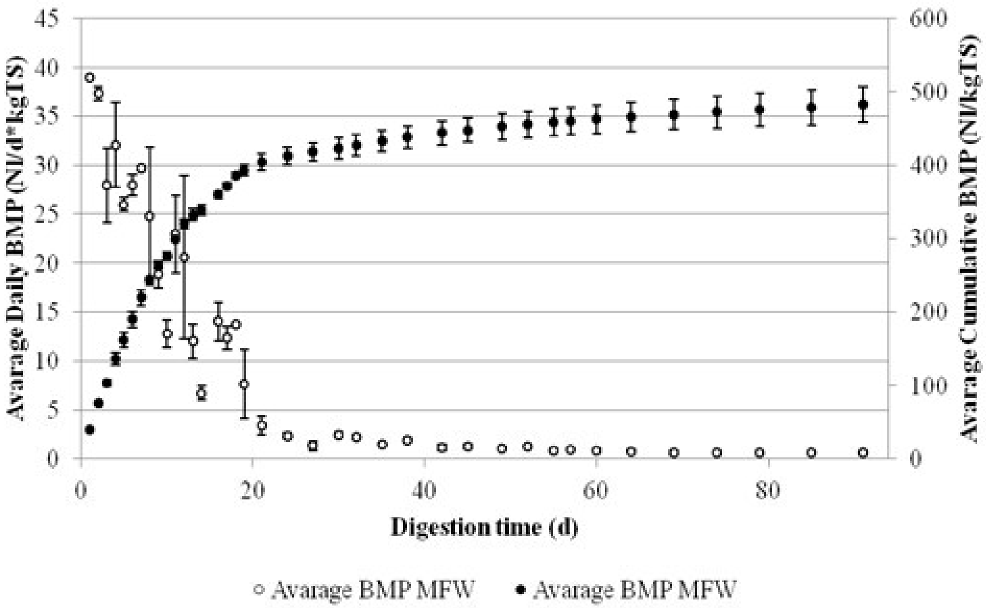

Fig. 5: Daily and cumulative BMP, Mixed Food Waste

As said before, the composition of the sampled biogas has been routinely analysed. As shown in Fig. 6, the methane content in the biogas produced by the MFW, increases from the 20% to 65% until the 20th day of digestion and from the 30th remains constant around the 60%.

Also for the other samples, the biogas composition was analysed in order to understand if the methanogenesis phase was correctly taking place during the digestion process.

From the biogas analysis it has also been possible to esteem the quantity of methane totally produced, simply as the product between the biogas released and the methane percentage of its composition (Fig. 7). Considering an average methane percentage of about the 57%, it was esteemed a methane yield of 309 and 296 $NLCH_4/kgVS$ for the sample MFW (a) and MFW (b) respectively.

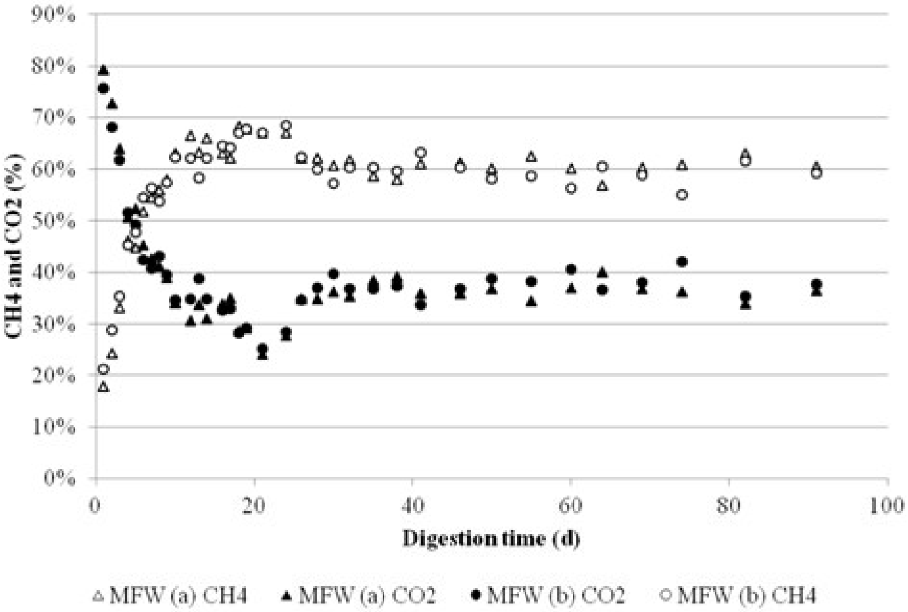

Fig. 6: MWF Sample biogas analysis

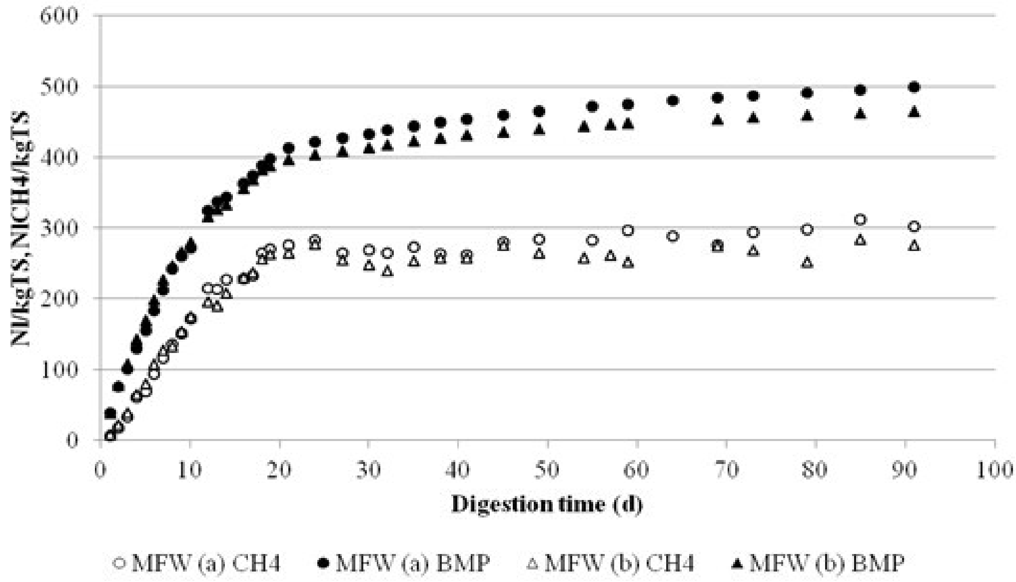

Fig. 7: MWF, BMP and CH4 production Comparison

As said before, the results obtained for the carbohydrates assay shows that the inhibition of the inoculum occurred. This is evident also looking at the errors behaviour (calculated as the ratio between the inoculums BMP and the BMP of each fraction) shown in Fig. 8. After 5 days, the biogas produced by the inoculums was the 20 % of the quantity produced by the sample, to become higher than the 120% at the 93rd day of digestion, which means a negligible biogas production from the substrate comparing with the one from the inoculums.

This is probably due to an accumulation of volatile fatty acid and acid conditions. In fact, in the preparation of the carbohydrates batches, too high concentrations of substrate were probably used, as well as the substrate to inoculums ratio was higher than 1,2, value suggested by the authors to avoid acidification[7] given that this ratio is recognised as one of the major parameter affecting the results of anaerobic assay[11].

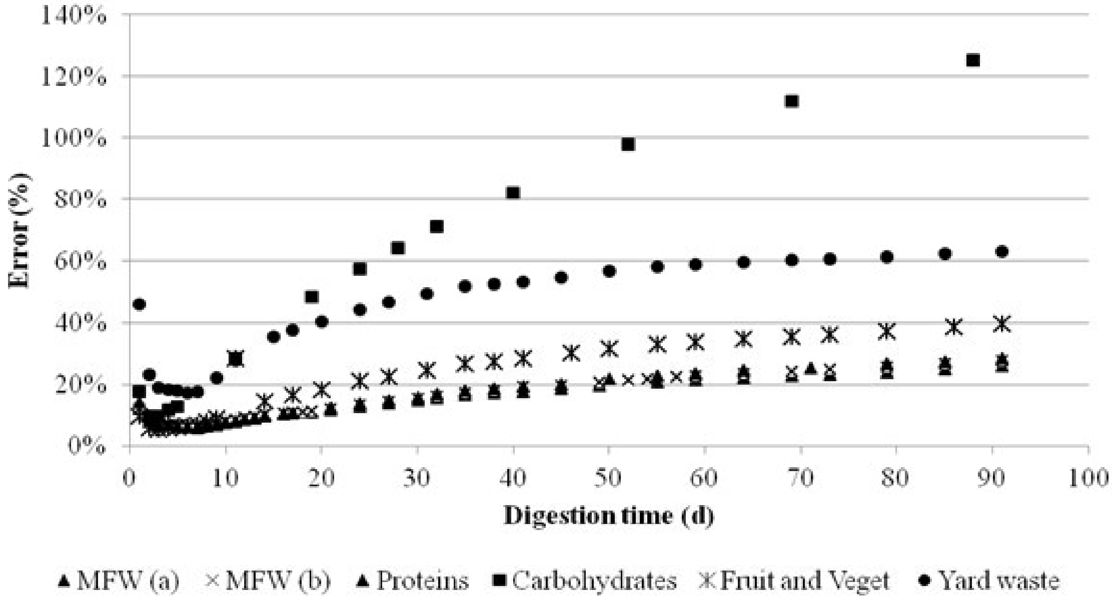

Fig. 8: Errors behaviour

Regarding the other substrates tested, the estimated errors were high too. After the 20th day of digestion, the BMP inoculum to BMP substrates ratio starts to increase until the 50th when all of them become higher than the 50%. This is probably due to a really high activity of the inoculum and an high VS content, as it is possible to observe in the average biomethane produced measured daily (Fig. 9): after 50 days the daily biogas production of all the substrates became comparable with the inoculum BMP.

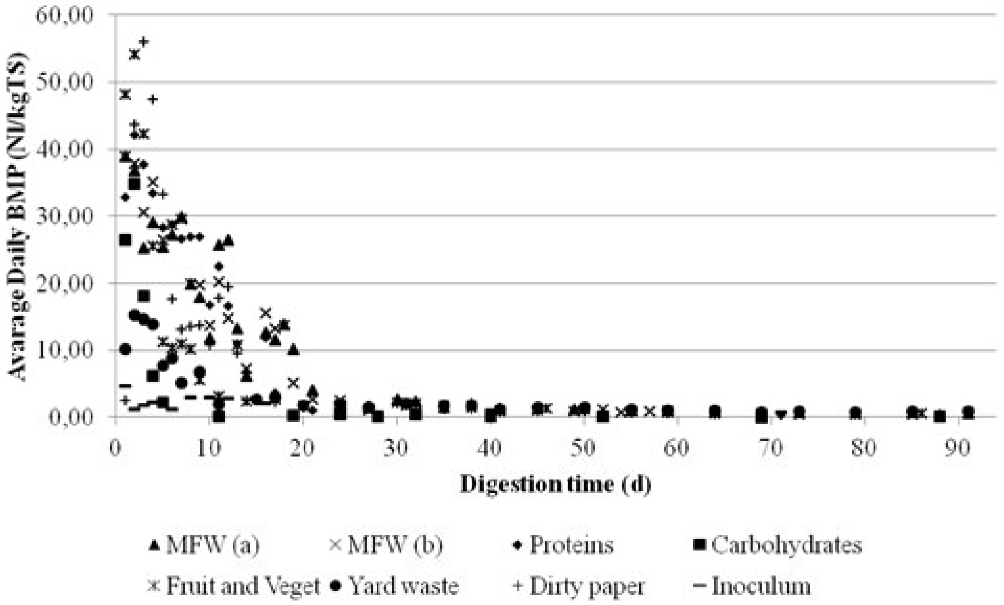

Fig. 9: Avarage Daily BMP comparison

As Fig. 5, the graphic in Fig. 9 shows that, comparing with the background methane production from the inoculum determined in blank assays, the biogas production after 40th day of digestion can be neglect and the most of the biogas was produced during the first 20th day of digestion. Furthermore, looking at the daily biogas pruduction,it can be noticed that, according with Zhu B., Gikas P. and Zhang R. et al. [7], the biogas production duration of food waste was prolunged, with initial daily biogas yields lower compare to others.

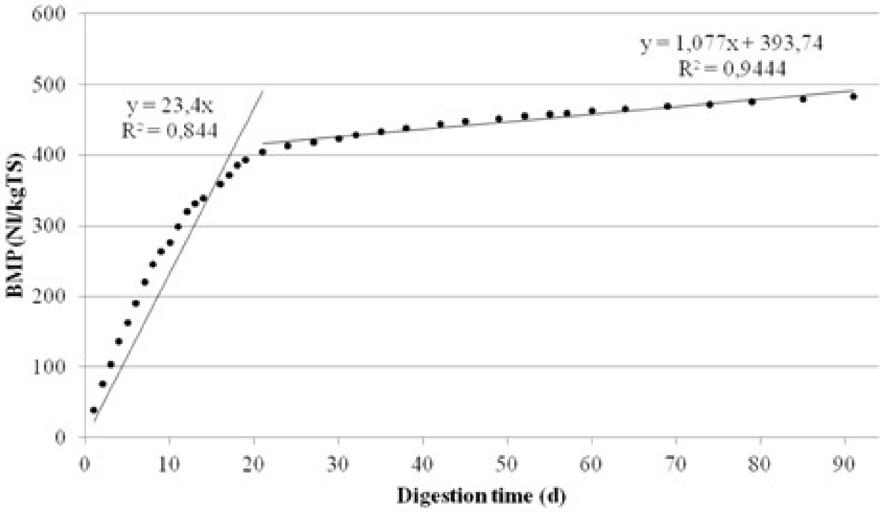

Fig. 10: MFW BMP schematization

With reference to the BMP measured for the mixed food waste samples, it is possible to find a good schematization of the biogas production. As show in Fig. 10, the curve could be well approximated by two lines with different slope. At the beginning the anaerobic digestion is faster and high biogas producing, but, after the meeting point of the two lines, anaerobic kinetics seems to be no more convenient given that the biogas production decreases and the biodegradation became really slow.

As suggested this raw model, for the first 20 days (first line) the anaerobic digestion seems to be a convenient treatment, after which (second line) aerobic stabilization process seems to be more suitable.

3.2. Industrial biogas production comparison

Moving from the results obtained from the tests, in order to compare the results with the biogas production from a real scale anaerobic digestion plant, it was calculated a specific BMP for a ton of input waste fraction (Table 5).

Table 5: BMP21 and BMPf for a ton of input waste

Experimental ID	*BMP21, Nm^3/t*	*BMPf, Nm^3/t*
MFW (a)	175	213
MFW (b)	168	198
Proteins	128	150
Carbohydrates	86	95
Fruit and Veget	35	46
Yard and Garden waste	7	13
Dirty paper	127	152
Inoculum	2	5

Adding up the BMP21 of each waste component and considering a typicall source selected OFMSW composition shown in Fig. 11, three potential industrial biogas production are define (Table 6):

- a maximum biogas production (GPmax), calculated assuming that the pre-treatment before the anaerobic digestion is able to remove only the undesired waste fractions with an efficiency of the 100%, i.e. wood packaging, plastic film and plastic packaging, other plastic, rubber, leather, ferrous and non ferrous metals, inert and hazardous waste;
- a potential production, in which is consider the 80% of pre-treatment efficiency and the 20% of biodegradable fraction removed wrongly (GP80%);
- another potential production defined as above but assuming an 75% removal efficiency and the 25% of organic fractions separate erroneously (GP75%).

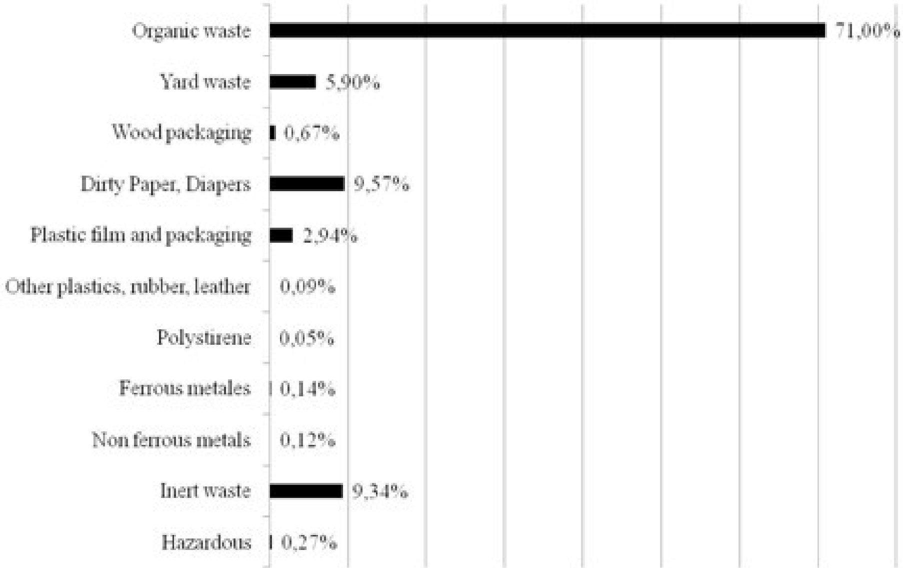

Fig. 11: OFMSW composition

Table 6: GPmax, GP80% and GP75% calculated values

Potential Industrial biogas production	*Removal efficiency, %*	*OF removed, %*	*Calculated value, Nm^3/t*
GPmax	100	0	134
GP80%	80	20	107
GP75%	75	25	100

These estimates could be compared with the biogas production of real anaerobic digestion plants (GPreal). In particular, two different anaerobic digestion plants are considered: one located in a rural area treating source selected OFMSW from a public collection point with a GP of 98 Nm^3/t, another located in a city area with a curbside collection system characterized by a higher GP (Table 7). It is possible to notice that the estimated biogas production (GP80% and GP75%) and the GPreal have similar values and that the rural area digester is characterized by the lowest biogas production.

Table 7: Biogas production, real industrial anaerobic digestion plant

Anaerobic digestion plant	*Collection system*	*GPreal, Nm^3/t*	*Data Source*
Rural Area	Public collection point	98	Management data
City Area	Curbside collection	108	Bozano Gandolfi P., [12]

As said before, during the experimental assay, it has been possible to measure also the BMP of the pre-treatment rejects. In particular the light fraction (LF) and the small heavy fraction (SHF) from the pre-treatment of the two anaerobic digesters were tested (Table 8).

Table 8: BMP21 of pre- treatment reject

Pre-treatment reject	*Provenience*	*BMP21, NL/kgVS*	*BMP21, Nm³/t*
LF	Rural Area	240	57
SHF		261	8
LF	City Area	508	99
SHF		214	33

As before, also the BMP21 of both LF and SHF form the rural area digester were lower than the ones from the city area. This is probably due to an high presence of yard and garden waste in the rural waste composition, given that the yard and garden waste has a low BMP21 (with reference to Table 5, 7 Nm³/t). On the other side, the rejects from the city area digestion plat are characterized by a high BMP21, probably because a considerable part of biodegradable fraction of input waste, with the highest BMP21, is wrongly removed by the pre-treatment.

5. Conclusions

The results of this study show that the biochemical methane potential assay could provide useful data to study the pre-treatment efficiency and the performance of real anaerobic digestion plant.

Focusing on the experimental work, the MFW had the highest biochemical methane potential, with an average BMP21 of 405 NL/kgTS and a BMPf of about 484 NL/kgTS and an average methane content of 57%. The laboratory equipments developed prove to be suitable to this kind of experimentation, given that no airtight problem occurred. However, the results obtained for the carbohydrates sample and the errors behaviour show that the measurement protocol and the sample preparation have to be improved in some parts. In particular more attention and specific evaluation have to be done for the substrate to inoculum ratio as well as for the inoculum characteristics. Actually, the estimates obtained with the experimental assay were comparable with the biogas production of real anaerobic digestion plant and it has been possible to assess the pre-treatment efficiency and the performance of some real cases. From the comparison results that: the GP of the rural plant is affected by the presence of yard and garden waste, as it is also supported by the BMP of the pre-treatment rejects; the pre-treatment reject of the city area plant, that treats OFMSW collected by a curbside system, has a high BMP probably because a considerable biodegradable fraction is removed by the pre-treatment.

Nomenclature

BMP Biochemical Methane Potential, NL/kgTS or NL/kgVS

BMP Biochemical Methane Potential after 21 days, NL/kgTS or NL/kgVS

BMPf Final Biochemical Methane Potential, NL/kgTS or NL/kgVS

GP80% Industrial biogas production, considering 80% of pre-treatment efficiency, Nm³/t

GP75% Industrial biogas production, considering 75% of pre-treatment efficiency, Nm³/t

GPmax Industrial biogas production, considering maximum pre-treatment efficiency, Nm³/t

GPreal Industrial biogas production, considering existing real plants, Nm³/t

LF Light Fraction, anaerobic digestion plant rejects

MFW Mixed Food Waste

MSW Municipal Solid Waste

NL Normal litre

NTP Normal Temperature and Pressure conditions, 273,15K and 1 atm respectively

OFMSW Organic Fraction from Municipal Solid Waste

SHF Small Heavy Fraction, anaerobic digestion plant rejects

TS Total Solid, % v/v on wet weight basis

VS Volatile Total solid, %v/v on TS basis

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