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BMP TEST TO MONITOR SEASONAL EFFICIENCY OF DRY ANAEROBIC DIGESTION PLANT

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ABSTRACT

The lack of specific monitoring tools is a hurdle for dry anaerobic digestion plant performance studies. The work aims to suggest a solid-state BMP protocol to monitor the full-scale dry anaerobic digestion process of the organic fraction of municipal solid waste. Physicochemical analyses, biomethane potential, and biodegradability data of different seasonal mixes fed in the reactor are provided. The data collected showed the effectiveness of the dry BMP test to analyse the process efficiency and to estimate the potential methane production of the biowaste. The process efficiency (expressed as % of methane production) was estimated combining the experimental data (BMP) and the plant parameters (organic loading rate and specific methane production) in four different seasons (Autumn, Winter, Spring, and Summer). The methane production (MP) of the plant ranged from 70 to 90 % of the potential biomethane production measured at lab scale. From the data collected, the seasonal differences were due to input biowaste (organic fraction of municipal solid waste and lignocellulosic materials used as bulking agent in dry AD) and their biodegradability, which results in different volatile solids removal in industrial reactor. The approach provided may be useful to better manage the process in a dry anaerobic digestion full-scale plant.

1. INTRODUCTION

The European Member States produce about 88 million tons of bio-waste every year (Papa et al; 2022); improvements in the collection and treatment of municipal waste across Europe are advocated to achieve the EU recycling target of 65 % by 2035 (EEA, 2020). The biowaste treatment through anaerobic digestion (AD) is promising, and in the year 2022, Europe's biogases production (combined biogas and biomethane) amounted to 21 bcm (European Biogas Association, Statistical Report 2023).

Compared to wet anaerobic digestion, dry anaerobic digestion (AD) has a low energy requirement for heating and pumping, less effluent production requiring dewatering, higher volumetric methane yield, and it has been employed using various technologies in smaller reactors, single or multistage operations (Rocamora et al., 2020; Wang et al., 2023). However, the main critical issues regard the process stability; the higher organic loading rate could generate an accumulation of potential inhibitors (such as ammonia and volatile fatty acids), and the higher total solids could lead to a decrease in the methane yield (Wang et al., 2020; Wang et al., 2023).

The Kompogas' system originated in Switzerland in the 1980s; it is a modified horizontal plug flow system with a slowly rotating internal axial mixer. The adopted mixing system increases the contact between microorganisms and organic substrate and degases the digestate (DG) before removal; the total solids in the reactor are held in the range of 23-28% to facilitate the flow. Most of the existing Kompogas plants (about 70) are operative in Europe. From the literature data, the expected biogas yield of the reactor is about 100-150 Nm^3/ton of the feed material (Hayyat et al., 2024).

The monitored plant is located in Trentino province (Northern Italy), and treats organic fraction of municipal solid waste (OFMSW) and lignocellulosic green waste. The thermophilic dry AD process is carried out in two horizontal continuously stirred and mixed tank reactors (CSTR; D1 and D2; length 32 m) with a constant feed system (mixture of OFMSW and lignocellulosic material used as a bulking agent) for 21 days at 51°C (Bona et al., 2020). Part of the DG is recirculated back to the head of the system as inoculum, while the remaining part goes to the subsequent aerobic composting section, after addition with yard waste

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to balance the C/N ratio of the starting mix. The intensive bio-oxidation phase of the composting process occurs in eight aerated bioreactors, followed by the maturation phase in aerated static piles. Aerobic treatment of DG lasts about 24 days.

Process stability is a crucial operational challenge to ensure plant productivity and efficiency (Cruz et al., 2021). Several recent works have focused on developing a proper monitoring plan (Cruz et al., 2021) with many parameters considered as stability indicators (pH, alkalinity, volatile fatty acid concentrations, biogas composition, methane yield, concentration of CO_2, H_2, aromatic compounds, enzymatic activity, and microbial community (Awhangbo et al., 2020). These parameters are useful to plan operational practices and to manage the reactors correctly. Moreover, the evaluation of the efficiency of the process is important to verify that a reactor is operating at its maximum potential. In a nutshell, monitoring of full-scale plants is strongly recommended to ensure proper management, energy optimisation, and biological stability, but with some challenges.

Firstly, the biomethane potential (BMP) assessment is a valuable tool in AD studies but, as previously detected, there is a lack of standardized protocol and data reporting in performing BMP tests (Hollinger et al., 2016; Oheneng-Ntiamoah and Datta, 2019; Filer et al., 2019). Furthermore, AD monitoring tools are mainly configured for the liquid and gaseous phases (Andrè et al., 2017). Therefore, data from BMP tests conducted under dry conditions, similar to those in industrial plants, could be used as practical indicators of process performance (Li et al., 2017). Some studies have investigated the scaling effect of methane production on specific substrates, and the comparison of bench-scale dry BMP results with full-scale biogas production seems promising (Schievano et al., 2011; Li et al., 2017). Moreover, the OFMSW is very heterogeneous along space and time: its composition in terms of biodegradable compounds (carbohydrates, proteins, and lipids) depends on several aspects, such as social and economic factors related to the food availability, seasonality, consumer customs, generating sources, collection time, and presence of touristic areas (Kobayashi et al., 2012). The work by Fisgativa et al. (2016) demonstrates that the geographical origin, the type of collection source, and the season might explain about 24% of the food waste variations, while more recent studies have shown the quantitative and qualitative seasonal effects of organic waste on the AD process (Edwiges et al., 2018; Mozhiarasi et al., 2019; Arhoun et al., 2019; Trujillo-Reyes et al., 2022).

This work aims to use a dry BMP test protocol at a bench-scale level to monitor the seasonal performance of a dry AD plant of OFMSW.

2. MATERIALS AND METHODS

2.1 BMP tests and seasonal biodegradability of the feedstock

The BMP test was assessed for the samples collected in the four seasons (Autumn 2017-Winter 2017-Spring 2018-Summer 2018). The tests were done in three 20-L experimental reactors modified to sustain a dry AD process with the biowaste mix used in the full-scale AD Kompogas plant. The protocol adopted was the same as described in Bona et al. (2020), by modifying the protocol described in Angelidaki et al (2011) and the German guideline VDI 4630 (2016). In a nutshell, a perforated stainless-steel basket was used in each reactor to guarantee proper gas exchange through the contained sample. The lab-reactors were heated at 51°C, the same operating temperature as the full-scale plant. The (net) biogas production is derived from the pressure changes measurement inside the reactor over time after the subtraction of the production ascribed to the inoculum, and expressed in (Nm^3CH_4/kg_{VS}) referring to the substrate VS.

The feeding mix was prepared with digestate as inoculum (stored and aged until stable production lower than <50 $NLCH_4/kg_{VS}$), screening green lignocellulosic material (SM) separated downstream the anaerobic and aerobic processes and used as a bulking agent (20% v/v), and OFMSW. The used materials were sampled in the plant at each season monitored. The VS ratio of fresh matter and inoculum was about 0.5 (inoculum to substrate ratio, ISR = 2). The measure of the biogas and biomethane production has been made with manometric approach. The methane produced has been measured by sampling 6 L of the produced biogas and analysing the biogas quality (CO_2, CH_4, O_2 and H_2S) by using a portable gas analyser (OPTIMA 7 BIOGAS, MRU Air Fair Gmbh).

The elemental composition (CHNO content) analysis has been assessed to calculate the theoretical stoichiometric biomethane potential (BMP_{th}), following the Buswell and Simons' equation to calculate the theoretical BMP_{th} (Symons & Buswell, 1933). The ratio between BMP_{th} and experimental BMP (BMP_{exp}) provides information about the % of biodegradability (α) of the organic matter content of the biomass considered. The % of biodegradability (α) was calculated for OFMSW each season, as in the following Equation 1.

$$\alpha = (BMP_{th}/BMP_{exp}) \cdot 100 \qquad (1)$$

The BMP results have been modelled as first-order kinetics for calculating the hydrolysis constant, using the following equation (2), in agreement with Gunaseelan (2004),

$$ln\ (BMP_{\infty}/BMP_{t}) = k_h \cdot t \qquad (2)$$

where the hydrolysis constant k_h (expressed in $days^{-1}$) depends on time t (here equal to the first 5 days considered for the calculation) and the natural logarithm of the ratio between the maximum value BMP_{∞} and the value measured after t days BMP_t (Gunaseelan, 2004).

The data were analysed by one-way ANOVA and multiple pairwise comparisons with Tukey formulation (level of significance α*=0.05). The BMP test results from different seasons were compared.

2.2 Seasonal monitoring plan of the full-scale AD plant

The full-scale plant was monitored yearly, from the Autumn 2017 until the Summer of 2018, considering five seasons: First Summer (June-July-August), Autumn

(September-October-November), Winter (December-January-February), Spring (March-April-May), Second Summer (June-July-August).

For each season, the data collected focused on (a) plant performance, (b) feedstock properties used for feeding digesters, and (c) the BMP of the mixes feeding in the reactors.

The feedstocks considered were OFMSW, recirculated DG as inoculum in the plant, and SM. The feedstock ratio feed in the plant was 60% OFMSW, 10% SM, and 30% recirculated DG on a mass basis. Each feedstock was analysed regularly (monthly), in pH, total solid content (TS), and volatile solids content (VS). The two stirred and mixed Kompogas-reactors were continuously heated at 51°C (+/- 1°C).

The biogas production, methane content in the biogas, and organic loading data of the plant were measured daily. Organic loading rate (OLR), Hydraulic Retention Time (HRT), and Specific Methane production (SMP) have been calculated both monthly and seasonally, related to the inflow VS mass of OFMSW and SM, indicated as VS_{in}, and to the working volume V of the reactor. The equations used were the following Equations (3-5).

$$OLR = VS_{in}/(V \cdot day) \quad (3)$$

$$HRT = V/\ VS_{in}/(V \cdot day) \quad (4)$$

$$SMP = Nm^3CH_4/VS_{in} \quad (5)$$

The Methane production potential (MP) of the real plant expected after the BMPs and the efficiency of VS removal (η) were assessed by applying the following equations 6-7 (modified from Hollinger et al., 2017), referring to the mass streams Q of VS related to OFMSW, SM, and DG, respectively (using the total volatile content indicated as $\%TVS_{OFMSW}$, $\%TVS_{SM}$, and $\%TVS_{DG}$, respectively).

$$MP\ (Nm^3CH_4) = Q_{VS} \cdot BMP \quad (6)$$

The efficiency of the process has been calculated as the percentage of the MP compared to total Methane production.

$$\eta = \frac{[(Q_{OFMSW} \cdot \%TVS_{OFMSW}) + (Q_{SM} \cdot \%TVS_{SM}) + (Q_{DG*} \cdot \%TVS_{DG})]_{IN} - [(Q_{DG} \cdot \%TVS_{DG})]_{OUT}}{[(Q_{OFMSW} \cdot \%TVS_{OFMSW}) + (Q_{SM} \cdot \%TVS_{SM}) + (Q_{DG*} \cdot \%TVS_{DG})]_{IN}} \quad (7)$$

Where the Q_{OFMSW} corresponds to the incoming flow of OFMSW, Q_{SM} corresponds to the lignocellulosic materials used in the feeding mix, and Q_{DG} corresponds to the digestate obtained downstream of the plant. The Q_{DG*} refers to the digestate fraction recirculated in the plant, in the feeding mix.

The proposed monitoring protocol for a dry-AD industrial plant, starting from lab scale development of dry BMP test, is shown in the following Figure 1.

3. RESULTS AND DISCUSSION

3.1 BMP results and biodegradability of the feedstock

The protocol adopted allowed the measurement of the BMP of OFMSW by simulating the conditions of the Kompogas reactors. The BMP data are in Table 1, and the cumulative BMP results are in Figure 2.

The BMP tests performed on dry conditions are challenging due to the lack of representative protocols and guidelines for very heterogeneous samples (Hollinger et al., 2016). The key issues concern the sampling methods, the inoculum origin concentration, storage and duration, and the different degradability of the lignocellulosic feedstock used as a bulking agent (Andrè et al., 2018). The obtained value (Table 1; Figure 2) agreed with the results of previous works on seasonal organic waste (Edwiges et al., 2018; Trujillo-Reyes et al., 2022) and dry AD tests (Sun et al., 2019).

As recommended, the inoculum came from an active AD plant to provide a stable, active, and diversified microbi-

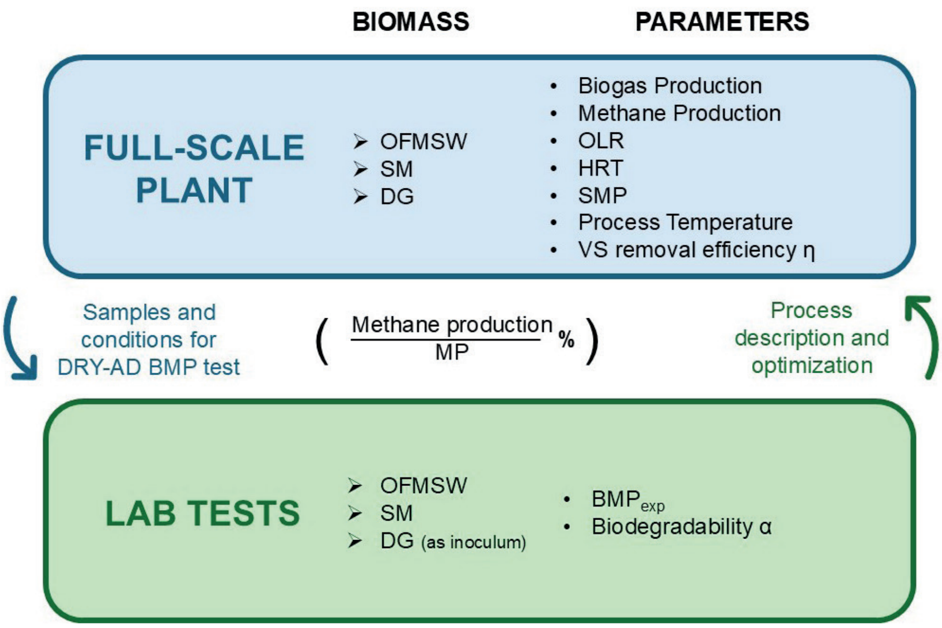

FIGURE 1: Scheme of the proposed monitoring protocol based on the development of a dry BMP test.

TABLE 1: Biogas production, BMP results, biodegradability (α), and hydrolysis constant (kh) for each monitored season (from Autumn 2017 to Summer 2018).

		Autumn	Winter	Spring	Summer
Specific Biogas Production	[Nm^3/kg_{VS}]	0.51 ± 0.09	0.57 ± 0.13	0.56 ± 0.02	0.59 ± 0.06
BMP	[Nm^3CH_4/kg_{VS}]	0.27 ± 0.05	0.31 ± 0.09	0.33 ± 0.01	0.30 ± 0.04
α	[%]	62 ± 12	73 ± 22	76 ± 2	71 ± 11
k_h	[1/days]	0.14	0.07	0.08	0.16

al community, taking care to maintain the same conditions of the plant (mainly temperature) with a very low endogenous methane production (<50 $NLCH_4/kg_{VS}$) (Hollinger et al., 2016). The choice of an adapted inoculum plays a crucial role in duration and methane rate measurement (Koch et al., 2017). The BMP duration was defined considering the validation criteria of previous works (1% of the ultimate methane production for 3 days) (Holliger et al., 2016; Hafner et al., 2020). Differently from wet BMP tests, in our protocol, the sample was not ground and shredded, because the sample's pretreatment could have altered the representativeness of the samples in dry conditions. Each sample was a result of the mixing of four different samples (collected in the plant) to achieve more reliability, and a greater volume of laboratory reactors have ensured the possibility of treating the inhomogeneous feeding mix (Ohemeng-Ntiamoah and Datta, 2019). The substrate concentration and inoculum to substrate ratio (ISR) was set up about 2 for each test; the value is also suitable for dry conditions to avoid a VFA accumulation and pH increase, hence biogas production affecting (Holliger et al., 2016; Ohemeng-Ntiamoah and Datta, 2019; Filer et al., 2019). The protocol adopted was useful to monitor the seasonal difference of the feedstock processed at the industrial plant. The data showed very slight variations among seasons; some differences between Autumn and Spring regarding biogas production, BMP and biodegradability are registered (even if not significant) (Table 1).

The ratio between easily degradable compounds and slowly degradable organics in the OFMSW could affect the BMP (Alibardi and Cossu, 2015). The composition and quantity of OFMSW have changed over seasons, and the presence of fruit and vegetable waste seems to be the main issue (Fisgativa et al., 2016). A recent study showed higher methane potential of OFMSW collected in Spring and confirmed the presence of a greater content of fruit and vegetables (Trujillo-Reyes et al., 2022). Similar results to those obtained in our work (which refers to the monitoring of seasons 2017/2018) were also achieved in this work, confirming the seasonal variability of waste composition and hence in AD performances (Trujillo-Reyes et al., 2022; Trujillo-Reyes et al., 2025).

Moreover, the concentration of lignocellulosic biomass in the dry process may result in the enrichment of hydrolytic and acidogenic microbes in the preliminary stages of the digestion, thus leading to high VS destruction and, subsequently, to a more apparent peak of biogas production than for wet AD (Brown et al., 2012).

The BMP was also performed on the SM of the plant to determine the degradability of the feedstock used as bulking agent in the mix feeding preparation. The RBP of SM was 0.034 Nm^3CH_4/kg_{VS} (degradability 8.88%) (data not

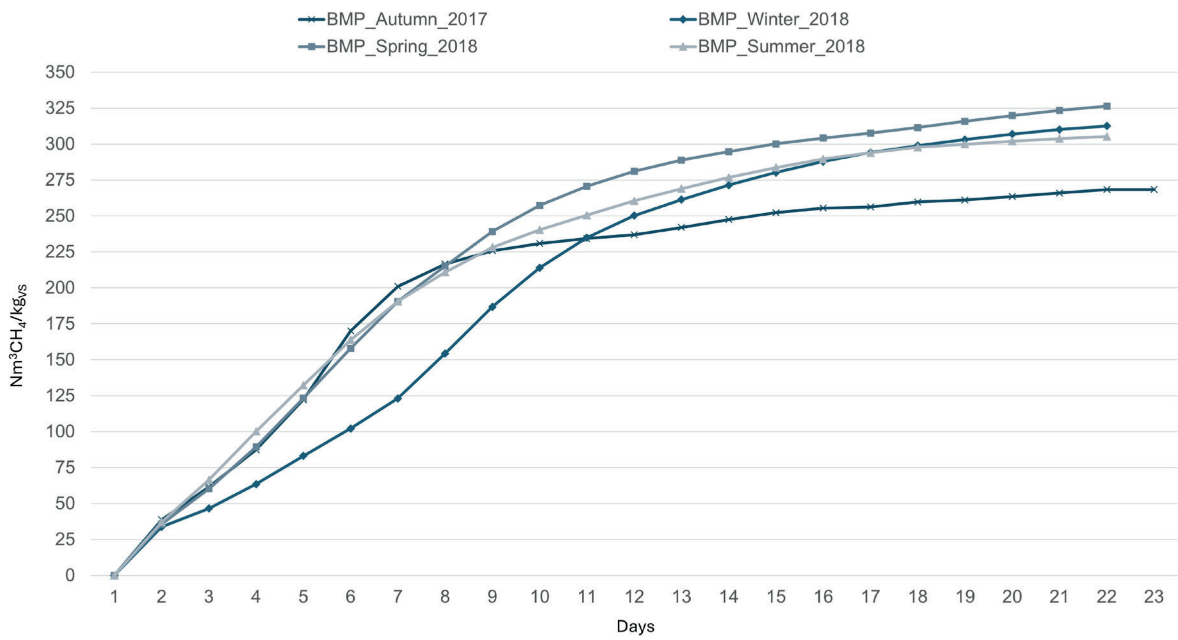

FIGURE 2: BMP cumulative results for OFMSW for each monitored season (from Summer 2017 to Summer 2018).

shown). The lignin content of SM can be a critical point in AD, since feedstock with high energy density compounds (such as lipids or easily degradable components of fruits and vegetables) have a higher BMP value and a higher biodegradability than compounds with high content of fibers (Li et al., 2013).

The first-order model used for modelling the methane production and at the same time the hydrolysis rate (k_h) of the feedstock can be linearized in agreement with Equation 2 (values shown in Table 1). The hydrolysis constant calculated for each seasonal BMP exhibits the same results of OFMSW degradability degree: the lowest hydrolysis constant value was in Autumn, while the highest was in Summer with slightly different kinetics among seasons. The calculated k_h values were inside the range of values reported in previous studies for thermophilic temperature, where methane productions occur faster than in mesophilic AD (Fernandez-Rodriguez et al., 2013). The difference between the Summer and Winter seasons on the k_h was probably related to the organic waste composition. According to previous results, first order kinetic constant of lignocellulosic biomass ranged from 0.08 to 0.09 1/d, fruit wastes ranged from 0.02 to 0.12 1/d, and vegetable wastes ranged from 0.05 to 0.13 1/d (Brown et al., 2012; Gunaseelan et al., 2004).

The feasibility of using BMP as a tool to analyses the process performances in the full-scale plant has been recently assessed, because it provides a good analysis of the anaerobic biodegradation potential of the organic matter in the prevailing reactor conditions (Li et al., 2017; Filler et al., 2019). Similarly, our work aims preliminarily to carry out an informative test, which allows us to consider the main dry AD issues, such as the different degradability of the lignocellulosic feedstock used as a bulking agent, the higher inhomogeneity of the feeding mix, and the mixing resistance (Wang et al., 2016; Ohemeng-Ntiamoah and Datta, 2019).

Holliger et al. (2016) and the subsequent work of Hafner et al. (2020) have defined some validation criteria for BMP data acceptance and evaluation (Hollinger et al., 2016; Hafner et al., 2020). According to these studies, even if the correlation with the cellulose BMP is moderate, the BMP data included in the range 340-395 $NmLCH_4/gVS$ can be accepted, thus making the "proposed dry BMP test" a reliable measurement and monitoring tool, which can be widely used (Hafner et al., 2020). Our BMP protocol considered some of these criteria, however, future work will provide tests to validate the BMP data in dry conditions, i.e., with positive control with cellulose.

3.2 Performance of the full-scale plant during monitoring seasons

The data about the performance of the full-scale plant samples are shown in Table 2 and the monthly data of SMP and OLR are shown in Figure 3.

The HRT values measured for each season ranged from 22 days in Autumn to 21 days in Summer (Table 2). The yearly mean value was 21.98 days. The VS removal efficiency (η) calculated for each season was higher in Spring and Summer than in Autumn and was about 70%. These differences are due to the composition and properties of organic waste. As seen before, the OFMSW of Autumn has lower BMP and biodegradability, which agreed with the lower VS removal as the full-scale plant monitoring showed. The higher content of lignocellulosic compounds in waste made the organic matter less degradable. The SM differed in terms of VS content among seasons (Table 2) and the VS degradability was very low as well as for DG (Table 1). Lignin is the most recalcitrant fraction of lignocellulosic biomass, and it can significantly inhibit the hydrolysis of holocellulose (Li et al., 2021).

In Summer, the VS (expressed in Mg) of OFMSW and SM were higher compared to Autumn and Winter, highlighting the seasonal differences of both quantitative and qualitative organic waste collected (Table 2), in agreement with similar study (Le Pera et al., 2021)

The SMP of the plant was higher in the Autumn and Winter (about 0.36 Nm^3CH_4/kg_{VS}) compared to Summer (about 0.30 Nm^3CH_4/kg_{VS}) as in Figure 3. The OLR (of OFMSW) calculated for each month was higher in the Winter and Sum-

TABLE 2: Data of dry AD full-scale plant monitoring (from Autumn 2017 to Summer 2018).

			Autumn	Winter	Spring	Summer
OFMSW	DM	[%]	31.5 ± 1.4	33.8 ± 1.4	37 ± 3	37 ± 6
	VS	[$\%_{DM}$]	73 ± 7	72 ± 7	65 ± 7	74 ± 5
	pH	[-]	4.72 ± 0.06	5.7 ± 0.4	5.4 ± 0.4	5.1 ± 0.7
SM	DM	[%]	68 ± 3	68.07 ± 0.05	68 ± 3	70 ± 6
	VS	[$\%_{DM}$]	60 ± 7	56 ± 3	67 ± 7	73 ± 5
	pH	[-]	8.85 ± 0.25	8.94 ± 0.16	8.74 ± 0.18	8.93 ± 0.02
DG	DM	[%]	31 ± 7	28.6 ± 1.2	26 ± 3	27 ± 0.8
	VS	[$\%_{DM}$]	51 ± 7	52 ± 3	55 ± 3	56 ± 5
	pH	[-]	8.40 ± 0.15	8.61 ± 0.03	8.61 ± 0.28	8.33 ± 0.15
VS_{OFMSW} IN		[Mg]	530 ± 80	610 ± 80	600 ± 30	680 ± 60
VS_{SM} IN		[Mg]	170± 40	170 ± 40	200 ± 30	220 ± 60
HRT		[day]	22 ± 1	22 ± 5	22 ± 2	21 ± 3
η - VS removal		[%]	65.78	68.46	72.45	71.25

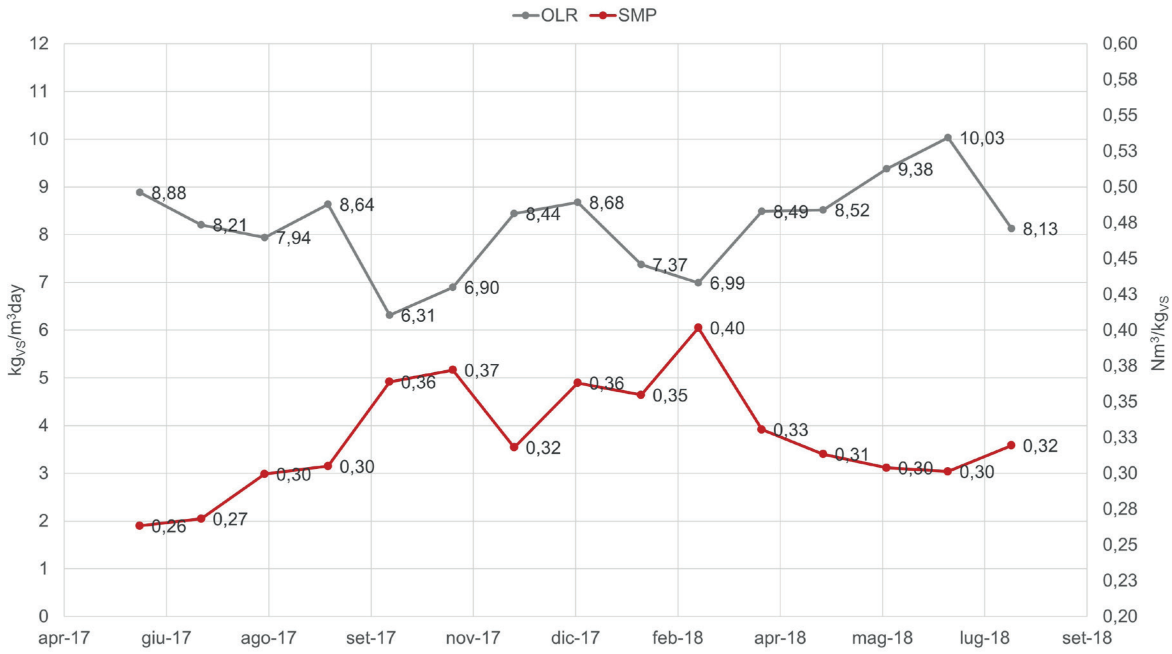

FIGURE 3: SMP and ORL of full-scale dry AD plant during the monitoring seasons (from Summer 2017 to Summer 2018).

mer months, (particularly in November, December, June, and July) (Figure 3) for both quantitative and qualitative differences. The reported data highlighted the effect of a better SMP and process performance in correspondence to lower OLR (Figure 2) and higher HRT (Table 2). The OLR results were slightly lower than those of other dry mesophilic AD plant (Le Pera et al., 2021).

The BMP results were used to calculate the seasonal MP values. Each MP value was compared to the effective methane production of the plant (data collected monthly from the full-scale plant monitoring). The percentage reported in Table 3 represents the average of the efficiency of methane production calculated for each season.

The efficiency of methane production MP (Equation 6) was better in Autumn; the methane production of the dry full-scale plant was in line with the BMP results (Table 2; Table 3). The reasons are due both to better process performance in full-scale plant and to the lower BMP of the OFMSW in Autumn. The data collected so far suggest that the better performance of the process in Autumn was due to both a the lower seasonal ORL and the lower seasonal BMP, corresponding to an overall lower content of available highly degradable organic matter. On the other hand, in the Spring and Summer, the higher OLR and lower HRT determined lower yields. Still, the higher methane potential and biodegradability of the OFMSW could have affected the process.

In recent years, many works have aimed to improve the knowledge of dry AD and the analysis of the performance of the process at full-scale (Li et al., 2019; Rocamora et al., 2020; Zou et al., 2022). The BMP tests could provide useful information for full-scale process efficiency monitoring; recently it has been assessed that BMP is suitable to estimate the methane production of an industrial AD, which is expected to be about 80-90% of MP (Holliger et al., 2017). In our work, this value ranged from 70% (in Summer) and 90% (In Autumn).

From the data collected, the operational management and good biological process resilience managed the qualitative and quantitative changes in incoming organic waste. Similar studies demonstrated that the redundancy of the microbial groups, which occurs when the communities significantly differ in composition but carry out similar roles, was considered as the best strategy to ensure the stability of methane production (Niu et al., 2015; Andrè et al., 2016; Pasalari et al., 2021).

The BMP-based indicator allowed the analysis of the quantitative and qualitative variability of biowaste, considering its anaerobic degradability, and it has been identified as a reliable monitoring system to assess the full-scale performances, as detected previously in the wet-condition AD plant (Li et al., 2017). Integrating the organic matter removal (based on the analysis of feedstock and digestate), and the theoretical methane yield with the biodegradability assessment allows a better understanding of the anaerobic biodegradation potential of biowaste. The results of the work will be useful developing the dry-BMP as monitoring tool. In a nutshell, the work confirms the importance of

TABLE 3: Percentage of the Methane produced at the full-scale plant over the Methane Potential (MP) for each monitored season (from Autumn 2017 to Summer 2018)

		Autumn	Winter	Spring	Summer
Methane: MP	[%]	94 ± 4	80 ± 3	84 ± 10	69 ± 8

proper knowledge of the feedstock in combination with the knowledge of process operations to ensure a stable dry AD process (Rocamora et al., 2020).

4. CONCLUSIONS

The work suggests an approach to perform a dry batch test to monitor the performance of a full-scale AD plant. The monitoring plan of a dry AD full-scale plant, based on the development of dry BMP test can obtain data on the efficiency of the biological process in the industrial reactor, linking the measure of OLR, SMP, and HRT at plant level, and BMP and biodegradability from lab scale test. The data highlighted slight seasonal differences (in plant performance, biodegradability, and BMP), probably related to the organic waste composition and the different lignocellulosic input and content of the organic mix fed into the plant. The plant operating conditions help in maintaining high performances in terms of biogas production. The BMP results give information about the degradability of the feeding mix and can be used to improve the operational management of the plant.

Combining the knowledge (qualitative and quantitative) of all the input feedstock loaded in the plant with the data of the monitoring plan results in a management method helps to predict the plant performances and to ensure the stability and efficiency of the biological process. Future works and data on the lab scale dry BMP test will strengthen the results obtained and hence can validate the dry BMP as a widespread application protocol.

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