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Biogas production from different substrates in an experimental Continuously Stirred Tank Reactor anaerobic digester

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ABSTRACT

Different mixtures were digested in a single-stage, batch, mixed, laboratory scale mesophilic anaerobic digester at the Biomass Research Centre Laboratory (University of Perugia). The yield and the composition of biogas from the different substrates were evaluated and the cumulative curves were estimated. Two experimental campaigns were carried out, the first on three mixtures (chicken, pig and bovine manures), the second on animal and vegetal biomasses (chicken and cow manure, olive husk) with different inocula (rumen fluid and digested sludge). In the first campaign pig manure mixture showed the maximum biogas production (0.35 Nm^3/kg) and energy content (1.35 kWh/kg VS); in the second one the differences in produced biogas from the different inocula were analyzed: olive husk with piggery manure anaerobically digested as inoculum showed the higher biogas (0.28 Nm^3/kg VS) and methane yield (0.11 Nm^3/kg VS), corresponding to an energetic content of 1.07 kWh/kg VS. All data obtained from the laboratory scale anaerobic digester are comparable to the values in literature for several biomass and in particular for olive husk, dairy manure and chicken manure.

1. Introduction

The EU and Italy, subscribing to the Kyoto Protocol, are committed to reducing greenhouse gases; renewable energies play an important role in this process and in particular biomass could contribute in a significant way because it is a "carbon neutral" fuel. It could be employed for energetic conversion by means of different processes, such as biochemical or thermal-chemical ones, depending on the biomass characteristics.

The anaerobic process has been traditionally used for excess sludge digestion in wastewater treatment plants or for treating manure, achieving a biogas to produce energy.

The anaerobic digestion process is characterized by a series of biochemical transformations brought on by different consortia of bacteria: firstly, organic materials of the substrate-like cellulose, hemicellulose, lignin must be liquefied by extracellular enzymes, then is treated by acidogenic bacteria; the rate of hydrolysis depends on the pH, temperature, composition and concentration of intermediate compounds. Then soluble organic components including the products of hydrolysis are converted into organic acids, alcohols, hydrogen and carbon dioxide by acidogens. The products of the acidogenenesis are converted into acetic acid, hydrogen and carbon dioxide. Methane is produced by methanogenic bacteria from acetic acid, hydrogen and carbon dioxide and from other substrates of which formic acid and methanol are the most important (Chynoweth et al., 2001). The process is catalyzed by a consortium of microorganisms (inoculum) that converts complex macromolecules into low molecular weight compounds (methane, carbon dioxide, water and ammonia).

Nowadays the process is also convenient for generic residual biomasses, with high water content because the methane produced may be used as a renewable energy source, thus eligible for public funding allocation. The State of Art technology for high humidity content biomasses, such as animal residues and waste of the food processing industry, is the thermo-stabilized Continuously Stirred Tank Reactor (CSTR), with automatic mixing device and continuous monitoring of the process parameters (Temperature, pH) (Dinsdale et al., 1996; Brás et al., 2001; Gallert et al., 2003; Rani and Nand, 2003; Siegert and Banks, 2005; Koppar and Pullammanappallil, 2008; Appels et al., 2008). Significant by-products are wastewaters with high BOD content, currently used in agriculture as a fertilizer; nevertheless the current trend in Europe is to reduce the amount of nitrogen that can be delivered in fields (91/676/CEE), therefore more and more surface will be necessary depending on the composition of the wastewater.

The technical and economical feasibility of an industrial anaerobic digestion plant depends on how much methane is yielded and the purity and on the wastewater characteristics, due to biomass chemical composition and process variables (temperature, retention time, pH, etc.). These performances are often not available in the literature; thus this could entail an increase of the risk of

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Nomenclature

BAL	balance (%vol)
C	carbon content (%)
db	dry basis
H	hydrogen content (%)
HHV	High Heating Value (MJ/kg_{db}; kJ/kg_{db})
HRT	Hydraulic Retention Time (day)
LHV	Low Heating Value (MJ/kg_{db}; kJ/kg_{db})
M	moisture (%)
N	nitrogen content (%)
O	oxygen content (%)
OFMSW	Organic Fraction of Municipal Solid Waste
OMW	Olive Mill Wastewater
Q	energetic content of biogas (kWh/kg VS)
t	time (s)
V_{ex}	experimental volume (m^3)
TS	total solids (%)
VS	volatile solids ($\%_{db}$)
φ	density (kg/Nm^3)

investments due to excessive uncertainties in the design phase. From these premises, a laboratory scale digester was built at the Biomass Research Centre of the University of Perugia (Fantozzi et al., 2005), to experimentally derive the influence of biomass composition and process variable on methane yield.

The aim of the present paper is to describe the experimental device and the results of different measurements campaigns carried out in order to provide data about the biogas production, the methane yield and the energetic content of different substrates with and without inoculum.

A preliminary phase, concerning lake algae, was carried out in order to evaluate if the biogas production was significant in a simplified system (Fantozzi et al., 2005).

Secondly a first experimental campaign was conducted, in which different substrates were investigated by means of experimental tests in the pilot anaerobic digester: poultry litter (diluted in water); bovine manure (diluted in water); mixture of chicken and pig manure from a local digestion plant; the chemical and physical characterization of biomass before and after the digestion process were also carried out.

A second experimental campaign was finally carried out, in which the yields of biogas and methane particularly from different kinds of biomass and inoculum were analysed. The inocula were selected according to criteria of availability, convenience and ease of use. Accordingly with the literature, tests were run using previous experiments digestate and rumen fluid. The digested substrates were of two typologies: manure (chicken and cow) and agricultural residues (olive husk) at mesophilic conditions ($T = 35$ °C).

In both experimental campaigns, the daily biogas production and the related cumulative curve were evaluated; samples of biogas were periodically analyzed to evaluate the methane percentage and the energetic content. Finally the biogas productivity was normalized with respect to humidity content and to volatile compounds content, in order to compare data related to the different substrates.

2. Methods

2.1. Experimental device

Literature is lacking biogas production data from different substrates; therefore a laboratory pilot digestion plant was built at the Biomass Research Centre of the University of Perugia. Before its construction, some preliminary activities in a simplified system were carried out to evaluate the possibility of biogas production in glass vessels into a climatic chamber. Analytical results show a good methanisation capacity of Trasimeno Lake algae, with significant variation depending on feedstock, some species showing a methane production of about 60% volume (Fantozzi et al., 2005).

A pilot batch digester was therefore designed and built (Fig. 1); it is a cylindrical vessel equipped with an airtight lid; the steel AISI 304 vessel has a working volume of 17 l, with 30 cm inner diameter and a height/width ratio of 5/6. Steel AISI 304 was used as building material for its strength and durability in acid or basic environments. Flexible silicon rubber heaters, with a maximum operating temperature of 260 °C and an electrical power density of 12.5 W/cm^2 (depending on temperature) are fitted on the external surface of the vessel, to heat and to maintain the feedstock at the required temperature. The heating system is equipped with an AF thermocouple, connected to a PID temperature controller; it is introduced in the digester through a hole on the lid, and closed by threaded steel adapter. Five holes are drilled on the lid of the digester: four side holes are used to insert temperature and pH probes through threaded steel adapters and rubber stoppers to avoid gas leakage. A stirring system RW 16 Basic IKA with a speed range of 40–1200 rpm was introduced, to allow mixing the feedstock and therefore increasing biogas production, as in existing CSRT plants. Finally the digester was equipped with a tap placed at the side, to collect the biogas produced.

Fig. 1. The anaerobic digester pilot plant of CRB.

The tap is connected to a dedicated gas storage system, designed and built to measure the quantity of biogas produced; it is made of two cylindrical coaxial chambers which communicate with each other, as shown in Fig. 2. The biogas produced can be sampled for measurement purposes through the tap or else it is stored in the gas meter that also allows to measure the volume through the indirect measurement of a liquid column height.

The error on biogas volume is a function of the error of the level measuring sensor and of the ratio between the gas storage system and the liquid column diameter. A homemade software was developed to evaluate the measurement error on biogas volume as a function of the above mentioned quantities and of time (Fantozzi et al., 2005). Data management and control are acquired by a digital system and a purposely-developed software. The system, constituted by the digester, the gas storage system and all the fittings is contained in a transportable and impermeable box ($160 \times 90 \times 210$ cm), in compliance with the current normative; it is provided with openings for air circulation and system security.

The produced biogas is characterized by a gas analyzer which allows to measure the volume percentages of CO_2, CH_4, O_2, H_2S, CO in the mixture. Before the onset of the anaerobic process, each substrate characterization is also carried out (Buratti et al., 2005), by a TruSpec-CHN LECO analyser for Ultimate Analysis (carbon, hydrogen and nitrogen content) and a TGA 701 LECO analyser for Proximate Analysis (humidity, volatile compounds and ash content), in compliance with CEN/TS 14774/1-2-3; CEN/TS 14775; ASTM D5373; UNI 10458.

Organic Fraction of Municipal Solid Waste (OFMSW) was chosen as a substrate for digester calibration; experimental results were compared to data from the literature (Vavilin et al., 2004), finding a similar trend (Fantozzi et al., 2005).

2.2. Experimental campaigns

The process of anaerobic digestion is used usually for animal manure and many examples are cited in the literature (Chynoweth et al., 2001; Gunasellan, 1997; Torres-Castillo et al., 2005; Salminen and Rintala, 2002; Lopes et al. 2004; Bouallagui et al., 2005). Different animal manures were considered; before the experiments, tap water was added to the substrate, in order to improve the moisture content and to enhance the process, according to the literature (Chynoweth et al., 2001; Gunasellan, 1997). Many residues of cultivation are also used in the anaerobic digestion processes (maize, vegetable waste,...) in co-digestion with animal manure to improve biogas yields. Nevertheless, few examples exist in the literature (Ali Tekin and Coskun Dalgic, 2000) about the anaerobic digestion of olive husk, while in Italy olive cultivation is very popular as in the other Mediterranean Countries and the olive oil production has increased during the last 30 years.

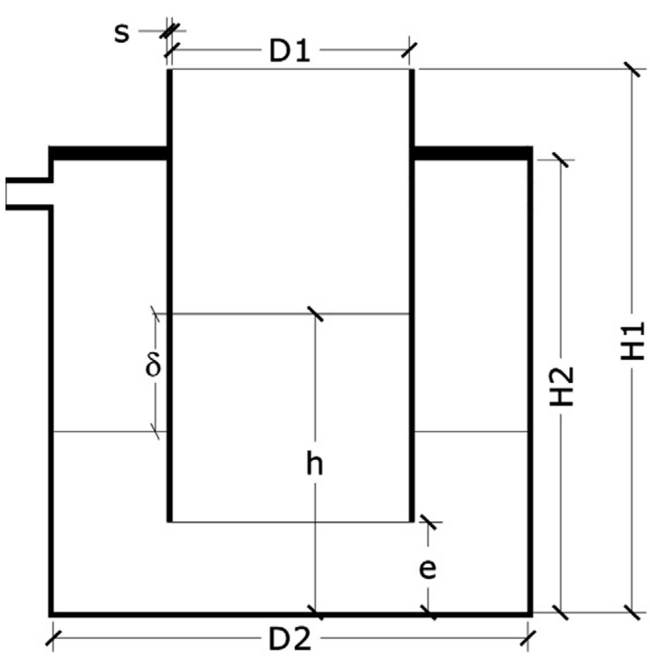

Fig. 2. The structure of the gas-meter.

Two experimental campaigns have been carried out until now so far; reactor temperature, pH and biogas production were monitored during all the tests. For each test the chemical and physical characteristics of the substrate were carried out (Buratti et al., 2005).

In the first experimental campaign the following animal manure substrates were analysed in the pilot digestion plant:

(a) poultry litter (diluted in water);
(b) bovine manure (diluted in water);
(c) mixture of poultry litter and pig manure from a local digestion plant.

In the second experimental campaign, the influence of the inoculum was investigated, considering an animal and a vegetal substrate; the following mixtures were considered:

(a) M1: cow manure with piggery manure anaerobically digested as inoculum;
(b) M2: chicken manure with piggery manure anaerobically digested as inoculum;
(c) P1: olive husk with piggery manure anaerobically digested as inoculum;
(d) P2: olive husk with rumen fluid as inoculum.

The aptitude of the substrates was finally verified evaluating the energy content of the biogas considering the biogas production per unit mass of organic substance (dry and ash free matter) and the methane percentage (a Lower Heating Value LHV_{CH_4} of 50,000 kJ/kg and a density of 0.715 kg/m^3 φ_{CH_4} were assumed for methane):

$$Nm^3_{CH_4} \times \varphi_{CH_4} \times LHV_{CH_4} = Q \quad (1)$$

The efficacy of the bio-technological anaerobic process in the nitrogen Load reduction was finally verified, in order to propose the process for the 91/676/CEE accomplishments.

3. Results and discussion

3.1. First experimental campaign

The substrates examined in the first experimental campaign (animal manure) were diluted in water and analysed before the biogas production test (Proximate and Ultimate Analysis).

Test on poultry litter lasted 30 days (see Fig. 3), in mesophilic conditions (36 °C); 0.8 kg of poultry litter, 1 kg of digested matter and 3.4 kg of water were loaded into the digester and the initial humidity of the mixture was about 93%. Proximate and Ultimate Analysis of the mixture are reported in Table 1: humidity as received was about 53%, therefore dilution was necessary; the analysis on the substrate showed a C/N ratio of 0.23, very suitable for anaerobic digestion.

Test on bovine manure lasted 33 days (see Fig. 3), in mesophilic conditions (36 °C); 2 kg of bovine manure, 1 kg of water from di-

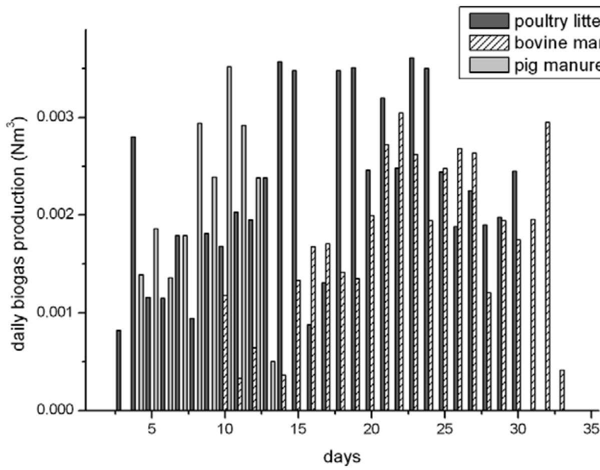

Fig. 3. Daily biogas production: poultry litter, bovine manure, pig manure.

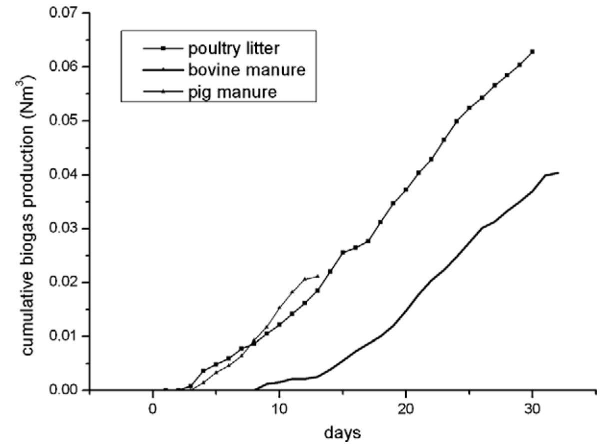

Fig. 4. Cumulative curve of biogas production: poultry litter, bovine manure, pig manure.

gested matter and 6.2 kg of water were loaded into the digester and the initial humidity of the mixture was about 92%. Proximate and Ultimate Analysis are reported in Table 1: the humidity as received was about 84% and it was diluted to reach the 92% value; the analysis on the substrate showed a C/N ratio of about 16, also suitable for anaerobic digestion.

Test on the mixture of poultry litter and pig manure from a local digestion plant lasted 13 days (see Fig. 3), in mesophilic conditions (36 °C); the mixture was constituted for 80% of pig manure, 15% of poultry litter and 5% of slaughter blood; only a low quantity of digested residual was added because the mixture humidity was high, in fact from results of Proximate Analysis a Humidity as received of 98% was found (see Table 1). From Ultimate Analysis, a C/N ratio of 1.04 was found, very suitable for anaerobic digestion.

The daily production trend and the cumulative curve for the three mixtures are sketched in Figs. 3 and 4.

The mixture with poultry litter showed the maximum values of biogas production between the 13th and 25th day and the total biogas produced was 6.28×10^{-2} Nm^3; the main components of the produced biogas are reported in Table 2; the maximum percentage of methane was 66% in volume while the anaerobic conditions were maintained throughout the test: a 0% concentration of O_2 was indeed found. The nitrogen load abatement was evaluated by means of Ultimate Analysis on digested matter at the end of the test (values with [a] in Table 1); the abatement, from 2.80% to 0.39%, was more than 86%.

The mixture with bovine manure showed a null value of the daily biogas production (Fig. 3) for the first days, due to the low concentration of bacteria; then the produced biogas increases with bacteria concentration and their metabolism. The cumulative curve (Fig. 4) gives a value of 4.17×10^{-2} Nm^3 of produced biogas; the methane percentage increases until a maximum of 46.5% (Table 2); Ultimate Analysis on the digested matter (values with [a] in Table 1) shows a reduction of the carbon content (from 6.86% to 2.85%), due to the production of methane and carbon dioxide, an increasing value of hydrogen (from 6.78% to 10.35%), due to the added water, and a reduction of more than 50% of the nitrogen content (from 0.44% to 0.19%).

The test on the mixture of chicken and pig manure showed a quick beginning of biogas production (Fig. 3); the cumulative curve (Fig. 4) gives a value of 2×10^{-2} Nm^3 of produced biogas. The methane percentage increased during the test, reaching a maximum value of 45.5% (Table 2); Ultimate Analysis on digested matter (values with [a] in Table 1) showed a carbon content reduction (from 0.78% to 0.31%), due to the volatile compounds formation, such as carbon dioxide and methane, a hydrogen content reduction (from 11.87% to 9.73%) and a nitrogen content reduction of about 47% (from 0.75% to 0.40%).

Poultry litter and bovine manure have similar Hydraulic Retention Time (HRT equal to 30 and 33 days respectively), while the mixture with pig manure has a lower HRT value, equal to 13 days (Table 3); they were in fact carried out until a significant methane increase in percentage. Table 3 also shows the results in terms of biogas and methane yield per kg VS; the highest methane yield was found for the pig and chicken manure mixture (0.13 Nm^3/kg VS). The corresponding energy produced by the gas, evaluated considering the LHV of the methane, was 1.35 kWh/kg VS.

3.2. Second experimental campaign

The mixtures of the second experimental campaign were chosen considering the state of art in the literature; the manufacturing

Table 1
Proximate and Ultimate Analysis results for the different substrates.

	Poultry litter	Bovine manure	Pig and chicken mixture	M1	M2	P1	P2
Humidity as received (%)	52.75	84.31	98.53	84.32	52.75	77.39	78.08
Volatile compounds (% db)	74.30	77.05	61.20	1.73	35.14	15.96	18.10
Ash (% db)	24.82	11.96	13.63	12.08	11.60	4.25	1.01
Fixed carbon (% db)	0.88	10.99	25.17	6.86	0.88	2.41	2.66
C (% wb)	0.65 (0.68[a])	6.86 (2.85[a])	0.78 (0.31[a])	6.78	15.39	9.52	12.68
H (% wb)	9.14 (11.60[a])	6.78 (10.35[a])	11.87 (9.73[a])	0.44	9.14	6.15	8.48
N (% wb)	2.80 (0.39[a])	0.44 (0.19[a])	0.75 (0.40[a])	0.44	2.80	0.17	1.99
C/N	0.23	15.59	1.04	16.00	5.50	75.85	6.40

[a] Data referred to digested matter; M1: cow manure and inoculum (piggery manure anaerobically digested), M2: chicken manure and inoculum (piggery manure anaerobically digested), P1: olive husk and inoculum (piggery manure anaerobically digested), P2: olive husk and inoculum (rumen fluid).

Table 2
Analysis of biogas from animal manure.

Compound	Day							Unit
	11	13	15	21	24	27	29	
Poultry litter								
CH_4	30.9	48.0	56.7	66.4	66.6	63.4	61.0	%vol
CO_2	66.4	48.3	38.8	28.5	27.3	26.5	24.8	%vol
O_2	0	0	0	0	0	0	0	%vol
BAL	2.7	3.6	4.5	5.1	6.1	10.1	12.2	%vol
H_2S	–	–	–	–	–	–	–	ppm
CO	–	–	–	408	383	256	276	ppm
	Day							
	15	18	22	24	30	32		
Bovine manure								
CH_4	15.4	16	21.6	34.6	46.5	44.5		%vol
CO_2	41.6	39.1	40.6	39.1	24.1	27.8		%vol
O_2	0	0	0	0	0	0		%vol
BAL	0	45	37.9	26.5	29.4	28.4		%vol
H_2S	550	–	–	–	–	20		ppm
CO	–	520	520	512	4	27		ppm
	Day							
	8	9	10	11	12			
Pig and chicken manure								
CH_4	31.2	35.5	38	38.8	45.5			%vol
CO_2	22.6	21.8	21.8	20.9	19.7			%vol
O_2	0	0	0	0	0			%vol
BAL	46.2	42.7	40.4	40.3	19.7			%vol
H_2S	–	–	410	–	–			ppm
CO	440	300	–	590	400			ppm

Table 3
HRT, biogas production, methane yield (v/v% and Nm^3/kg VS) and energy value.

	HRT (days)	Biogas (Nm^3/kg VS)	Methane (v/v%)	Methane (Nm^3/kg VS)	Energy value (kWh/kg VS)
PL	30	0.22	66.6	0.12	1.21
BM	33	0.15	46.5	0.04	0.41
PCM	13	0.35	45.5	0.13	1.35
M1	32	0.15	46.5	0.04	0.4
M2	30	0.22	66.6	0.11	1.2
P1	43	0.28	60.3	0.11	1.07
P2	46	0.08	57.6	0.03	0.18

PL: poultry litter; BM: bovine manure; PCM: pig and chicken manure; M1: cow manure and inoculum (piggery manure anaerobically digested), M2: chicken manure and inoculum (piggery manure anaerobically digested), P1: olive husk and inoculum (piggery manure anaerobically digested), P2: olive husk and inoculum (rumen fluid).

process of olive oil usually yields an oily phase (13–25%), a solid residue (37–50%) and an aqueous phase (35–50%); oil is separated by centrifugation, oil in the husks being recovered by solvent extraction (Rozzi and Malpei, 1996; Vito et al., 1999). The wash waters combined with the olive oil waters produce a waste by product, the Olive Mill Wastewater (OMW). The latter contains a major amount of organic matter (including aromatic compounds) which, in association to its high C/N ratio and low pH, compromise biological degradation processes (Marques, 2001). Anaerobic fermentation of the aqueous phase, which has a high BOD value, could be a way to convert the greatest fraction of OMW organic content into biogas.

Olive husk has a moisture value not suitable for the process, therefore it is necessary to add tap water, to obtain a slurry with a TS content of 5% to maximize the methane yield, according to data in the literature (Ali Tekin and Coskun Dalgic, 2000) and a good inoculum, such as piggery effluent from an anaerobic digestion plant (Marques, 2001), which was therefore considered in the present experimental campaign.

To establish the inoculum influence on the substrate behaviour, two sets of experiments were carried out, the first using the same inoculum for different substrates (piggery manure anaerobically digested from a plant), the second using the same substrate (olive husk and tap water, 5% TS with piggery manure anaerobically digested) (Marques, 2001) and rumen microorganisms. The piggery anaerobic sludge was collected from an anaerobic plant located near the University of Perugia. The second inoculum was rumen fluid obtained by squeezing the rumen stomach, provided by a nearby slaughterhouse. The rumen is an exclusive organ of ruminant animals in which the digestion of cellulose and other polysaccharide molecules occurs thanks to the activity of specific microbial populations. The capacity of cellulose digestion that these animals possess is related to the presence of anaerobic microorganisms in their rumen, that converts acetate part in methane and in carbon dioxide. The potential application of rumen cultures for anaerobic digestion of lignocellulosic materials was investigated in several papers (Torres-Castillo et al., 2005; Lopes et al., 2004; Zhen and Han Qing, 2006). The choice of this inoculum depends on the presence of ground olive stone in the olive husk, that increases the level of lignin in the substrate.

Therefore the four mixtures M1, M2, P1 and P2 previously described were examined.

The test on the mixture M1, constituted by cow manure and piggery manure anaerobically digested as inoculum, lasted 32 days; Proximate Analysis (Table 1) showed a value of humidity as received of about 84% while Ultimate Analysis showed a C/N ratio of 16, suitable for anaerobic digestion.

The test on the mixture M2, constituted by chicken manure and piggery manure anaerobically digested as inoculum, lasted 30 days; Proximate Analysis (Table 1) showed a value of humidity as received of about 53% while Ultimate Analysis showed a C/N ratio of 5.5, also suitable for anaerobic digestion.

The test on the mixture P1, constituted by olive husk and piggery manure anaerobically digested as inoculum, lasted 43 days; Proximate Analysis (Table 1) showed a value of humidity as received of about 77% while Ultimate Analysis showed a high C/N ratio for anaerobic digestion, equal to 75.85.

The test on the mixture P2, constituted by olive husk and rumen fluid as inoculum, lasted 46 days; Proximate Analysis (Table 1) showed a value of humidity as received of about 78% while Ultimate Analysis showed a C/N ratio of 6.4, suitable for anaerobic digestion.

The final biogas production of the mixture M1 was 0.15 Nm^3/kg VS, with a methane yield of about 0.04 Nm^3/kg VS; the mixture M2 showed a final biogas production of 0.22 Nm^3/kg VS while the methane yield was about 0.11 Nm^3/kg VS; the mixture P1 showed a final biogas production of 0.28 Nm^3/kg VS with a methane yield of about 0.11 Nm^3/kg VS; finally the mixture P2 showed a final biogas production of 0.08 Nm^3/kg VS while methane yield was about 0.03 Nm^3/kg VS (Figs. 5 and 6).

Tests of the second experimental campaign showed similar Hydraulic Retention Time (HRT) for mixtures with the same substrate (Table 3): mixtures with chicken manure had 32 days for M1 and 30 days for M2, while mixtures with olive husk had 43 days for P1 and 46 days for P2.

The substrates of the second experimental campaign were characterized by the same weight of inoculum (around 1 kg) and by the same weight of VS, in order to compare the results.

The P1 mixture (olive husk and piggery manure anaerobically digested) is characterized by the highest biogas production, which becomes equal to M2 (chicken manure and piggery manure anaerobically digested) after thirty days. Evaluating the methane production, M2 shows a higher production than P1; the production furthermore begins earlier, demonstrating that the coupling chicken manure and piggery digestate is more suitable.

The comparison between P1 and P2 (same substrate, olive husk, with different inocula) shows that the olive husk could be a good substrate for the anaerobic digestion process if coupled with a suitable inoculum, as the piggery manure anaerobically digested. The volume percentage of methane is not so different, but the biogas yield is lower.

All the data obtained in the pilot plant are comparable to the values in literature for several biomass (Chynoweth et al., 2001; Gunasellan, 1997) and in particular for olive pomace (Ali Tekin and Coskun Dalgic, 2000), for dairy manure (Morris et al., 1977; Bryant et al., 1976) and for chicken manure (Salminen and Rintala, 2002), as shown in Table 4.

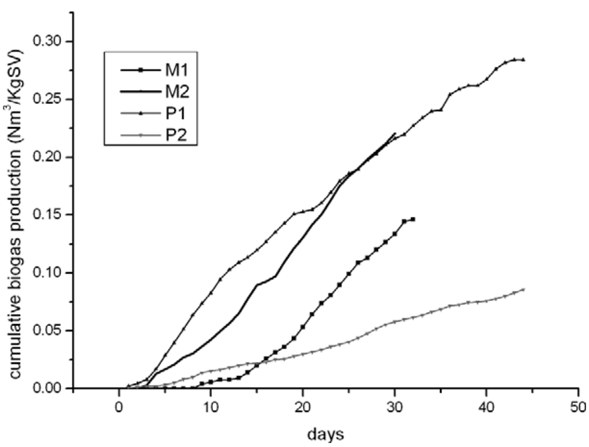

Fig. 5. Biogas production from different substrates using different inocula. (M1: Substrate: cow manure, Inoculum: piggery manure; M2: Substrate: chicken manure, Inoculum: piggery manure; P1: Substrate: olive husk, Inoculum: piggery manure; P2: Substrate: olive husk, Inoculum: rumen fluid).

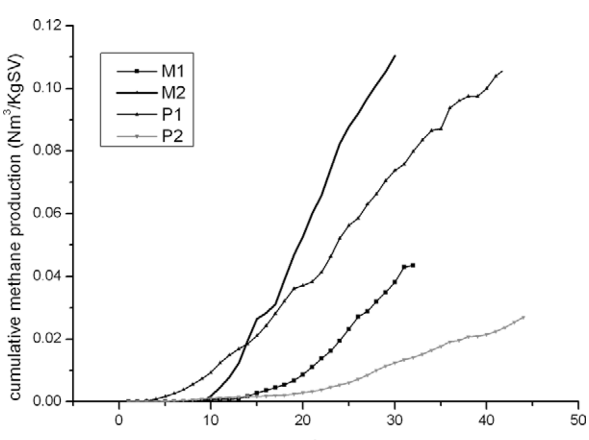

Fig. 6. Methane production from different substrates using different inocula. (M1: Substrate: cow manure, Inoculum: piggery manure; M2: Substrate: chicken manure, Inoculum: piggery manure; P1: Substrate: olive husk, Inoculum: piggery manure; P2: Substrate: olive husk, Inoculum: rumen fluid).

Table 4
Methane yield in the literature.

	Methane (Nm^3/kg VS)	References
Chicken manure	0.2–0.3	Salminen and Rintala (2002)
Cow manure	0.22	Morris et al. (1977)
Cow manure	0.17	Bryant et al. (1976)
Olive pomace	0.08	Ali Tekin and Coskun Dalgic (2000)

4. Conclusion

A single-stage, batch, mixed, laboratory anaerobic digester was designed and built to evaluate biogas production from different substrates: poultry litter, bovine and pig manure, olive husk; nitrogen content reduction in wastes was also evaluated. A good productivity for pig manure was found (0.13 Nm^3/kgVS) and a high reduction of nitrogen content (poultry litter: 86%). The influence of inoculum was also evaluated; when considering pig manure anaerobically digested and chicken manure the highest methane production was found (0.11 Nm^3/kgVS). When comparing pig manure to rumen fluid on olive husk, the first shows better performance (0.11 vs. 0.03 Nm^3/kgVS), coherently with literature.

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