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Mesophilic to thermophilic conditions in codigestion of sewage sludge and OFMSW: evaluation of effluent stability using dynamic respirometric index (DRI) and biochemical methane potential (BMP)

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The paper deals with the change from the mesophilic to thermophilic conditions in the codigestion process applied to secondary sludge from a biological nutrients removal (BNR) together with the organic fraction of municipal solid waste (OFMSW) or biowaste. The first part of the study was carried out at pilot scale in a 0.38 m^3 pilot scale plant, in order to evaluate the process behaviour during short-time meso-thermo passage and the relative yield increase. In the second part, the same set of operational conditions was applied to a full scale 2000 m^3 digester: both pilot and full scale trials evidenced the same behaviour and results. The thermophilic range of temperature showed a general increase of performance of about 50% in terms of biogas yields and allowed for a better stabilisation of the effluent (digestate). In order to evaluate this aspect, both the aerobic and anaerobic rate of stability was evaluated: the effective rate of stabilisation of the digested material by means of aerobic (Dynamic Respirometric Index), and anaerobic batch tests (Biochemical Methane Potential) was determined. Preliminary tests on the effluents originated from three plants showed a DRI lower than 1000 $mgO_2/kgVSh$ which is the minimum value required for a stable compost following the Italian regulation system, and an average SGP of 0,15-0,30 $m^3/kgVS$ which demonstrated a partial conversion of the organic matter into biogas.

1. Introduction

In order to improve the performances of anaerobic digesters, the co-digestion of waste activated sludge together with other organic wastes is a common practice adopted in wastewater treatment plants (Bolzonella et al., 2006a,b). Considering this scenario, more research work in strictly applicative fields (large pilot and full scale experiences) is needed to reach a wider application of this approach, which allows for the use of existing structures, saving in plant costs. The main lack of work can be identified in the optimization of the process, which is normally carried out at not adequate operative

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conditions or at low temperature. The scarce application of the thermophilic range, which allows for a better quality effluent and higher conversion yields respect to the mesophilic environment, is a typical example of this (Cecchi et al, 1993). In fact, the co-digestion of sludge with other easily biodeagradable substrates, food processing waste or agro-waste, allows for an increase of the loading rate as well as the biogas production,. Another important aspect to be considered in the co-digestion option is then related to the final fate of digestate. Usually, the effluent is dewatered and the solid part sent to composting or direct land application. However, when considering the post-composting option, it is important to emphasises that digestate is already a stabilised material and the time requested for the aerobic step could be therefore conveniently reduced. The aim of this paper is to give an overall evaluation of the global process considering not only the improvement of the yields determined by the thermophilic environment in the anaerobic reactor, but also the possibility to reduce the treatment time the dewatered sludge in composting plants, considering two different index: the dynamic respirometric index (DRI), and the biochemical methane potential (BMP).

2. Materials and methods

2.1 Treviso wastewater treatment plant features

The plant, is a 70,000 PE system adopting the BNR (Johannesburg scheme) process. Waste activated sludge is thickened to a 3% solids concentration and mixed with separately collected biowaste with a typical TS content of some 25% . The mixed biomass, with a typical TS content of 7-8 % is then sent to a wet mixer/separator where the floating residual materials and bottom residues are withdrawn. The diluted mixture is then sent to the 2000 m^3 mesophilic digester by a shredding pump, together with the rest of the excess sludge, fed daily on a continuous basis. Produced biogas is stored and used in a 190 kW_{ee} cogeneration unit for combined heat and power production (CHP).

2.2 Pilot plant features

The pilot digester used for the experimental trials was a 380 liters AISI 316 tank, fully insulated. Temperature was controlled by an external serpentine, water filled, through a PT100-based thermostat.

2.3 Substrates

The wastewater originated from Treviso Municipality and is mainly of civil origin. Excess sludge produced by the plant is only waste activated sludge. Table 1 resumes the main characteristics of biowaste.

Table 1. Characteristics of biowaste.

	average	min.	Max	Std.Dev
		OFMSW		
TS, g/Kg	224,1	208,0	243,0	14,38
TVS, g/Kg	189,3	175,0	209,6	14,98
COD, mg/l	207,8	172,5	233,0	27,09
TKN, %TS	6,4	5,4	6,9	0,69

2.4 Analytical methods
The chemical and physical-chemical analyses were performed according to the APHA Standard Methods (2003)

2.5 Biochemical Methane Potential (BMP)
The test was performed in 1 litre closed vessels, using as inoculum the digested sludge drawn from the full scale digester of Treviso's WWTP. Every test was carried out in double and the background methane production from the inoculum was determined in blank assays and subtracted from the methane production obtained from the sample assays (Angelidaki et al, 2009). Another important parameter is the biogas composition, monitored daily by gas-chromatographic method. The GC used was provided with thermal conductivity detection (TCD) and a capillary column (HP-PLOT Q, 30,0m x 320 um x 20,0 um), and the gas carrier used is helium.

2.6 Dynamic Respirometric Index (IRD)
DRI was measured using an adiabatic respirometric reactor (Costech International, Cernusco S.N., Italy; DiProVe, Milan, Italy). The respirometer was composed of an insulated reactor, a control cabinet, an air supply system, and a PC unit. The O_2 concentration was set in order to guarantee 140 ml/l^{-1} in the outlet airflow (Adani et al, 2001). This value was maintained by a feed-back control that automatically adapted to airflow rate as a function of the O_2 concentration in the outlet airflow. The hourly index (DRIh) was determined by measuring the difference in O_2 concentration (ml/l^{-1}) between the inlet and outlet air flows. Between 10 and 16 kg of wet sample was used for the tests.

3. Results and discussion

3.1 Pilot scale tests and full scale implementation
The pilot scale reactor was seed with the effluent of the full scale digester. During the start up phase, from day 1 to 40 (run I), the digester was fed daily using only WAS. The OLR applied was 1.2 kgTVS/m^3d and the temperature of the reactor was mesophilic (35° C). In the second run, from day 40 to 60, the reactor was fed with WAS mixed with the OFMSW, in the same ratio applied to the full scale plant, simulating the same conditions (OLR 1,60 kgVS/m^3d). In the full scale plant the amount of OFMSW treated was 10 tons per day, half of the total amount treatable. After 1 HRT of steady state conditions, the feed was interrupted and the reactor temperature set at 55°C: the change was obtained in 24 hours. After 1 week without feeding, the digester was fed with half OLR (same WAS/OFMSW ratio) in order to support microorganisms adaptation. After 1 week, the OLR was raised to the full value (OLR 1,66 kgVS/m^3d, run III). A further period was studied, increasing the OLR to 2,21 kgVS/m^3d using the same quantity of WAS and doubling the quantity of OFMSW in the feed. This new conditions reproduced the same future loading conditions of the full scale digester, when the whole OFMSW production of the Treviso city will be treated (20 tons per day).
In general, VFA and pH showed the same levels for both mesophilic and thermophilic conditions while, on the other hand, alkalinity and ammonia concentrations increased constantly along the experimentation because of the increased hydrolysis of the particulate organic matter. Table 2 shows the main results obtained as average values in the different steady state conditions. The percentage of OFMSW indicated for each period are related to the total load needed for the service of the whole city, 50% for run II and III, 100% for run IV.

Table 2. Main results obtained in the different SSC at pilot scale

Parameter (referred to reactor content)	Period I Start-up (sludge)	Period II Mix, 50 % OFMSW(*)	Period III Mix, 50 % OFMSW(*)	Period IV Mix, 100 % OFMSW(*)
T, °C	37	37	55	55
OLR, $kgTVS/m^3d$	1,22	1,60	1,66	2,21
HRT,d	22.1	23.5	22.3	21.6
NH_3 gN/l	0,48	0,39	0,59	0,99
Alkalinity pH 6, $mgCaCO_3/l$	1223	1233	1544	2439
Alkalinity pH 4, $mgCaCO_3/l$	1973	1940	2570	3903
pH	7,3	7,6	7,7	7,8
VFA tot, mgCOD/l	19,0	36,4	52,6	43,0
TKN out gN/l	1,4	1,4	1,1	1,3
Ptot out g/l	0,8	0,6	0,8	0,7
SGP, $m^3/kgTVSa$	0,15	0,34	0,49	0,57
GPR, m^3/m^3d	0,18	0,53	0,78	1,24
CH_4, %	61,0	60,4	61,6	62,2

(*) As simulated percentage of the total load foreseen for the service of the whole city.

According to data reported in table 2, a clear increase of yields was obtained changing the temperature to thermophilic range: GPR values changed from 0.53 to 0.78 m^3/m^3 d, while SGP from 0.34 to 0.49 $m^3/kgTVS$ (47 and 44 % increase respectively) applying the same OLR to the reactor. This confirms previous results reported in literature (Cecchi et al, 1993, Mace et al., 2003; Mladenovska and Ahring, 2000), where the better performances of the thermophilic process when applied to organic wastes were mentioned several times. Considering these positive aspects, the same approach was applied to the full scale reactor. Table 3 summarises the main results of the full scale experimentation.

Table 3. Stability parameters and yields of full scale mesophilic and thermophilic anaerobic digestion

Parameter	Full scale,Mesophilic	Full scale, Thermophilic
OLR, $kgTVS/m^3d$	1,6	1,3
SGP, $m^3/kgTVSa$	0,35	0,55
GPR, m^3/m^3d	0,56	0,70
CH_4, %	60,0	60,0
TVS % removed	39,5	47,2
pH	7,2	7,6
TA(pH 4), $mgCaCO_3/l$	1775	2533
VFA, mgCOD/l	270,1	267,8
NH_3, mgN/l	0,42	0,69

The temperature change was carried out shortly (3 days). With reference to the stability parameters, the process followed the same behaviour obtained in the pilot tests. In terms of yields, GPR and SGP values replayed the evidence of the pilot scale: in the mesophilic range the values were practically the same (GPR: 0.53 vs 0.56 m^3/m^3 d, SGP: 0.34 vs 0.35 m^3/kgTVS), while in thermophilic range the full scale results were even better. In fact, the OLR applied in full scale was reduced if compared to pilot scale test (1.3 vs 1.6 kgTVS/m^3 d) and only for this reason the GPR value was reduced if compared with the pilot scale (0.70 vs. 0.78 m^3/m^3 d). The SGP value was higher (0.55 vs 0.49 m^3/kgTVS), instead. Clearly, the increased hydrolysis also determined a larger amount of ammonia released in the reject water recycled to the wastewater treatment line which partially reduce the benefits of the increase of biogas production.

3.2 BMP results

The BMP trials were carried out on dewatered sludge of the three plants for the AD of biowaste located in the Veneto region: Treviso, Camposampiero and Bassano. For the first two plants the tests were carried out both in mesophilic and thermophilic conditions. The results shown in table 4 are the average values of the specific gas production observed at the end of the test. It is possible to observe that the effluent material from the digesters still presented a residual methane potential: some 15-20% of the fed material SGP (some 0,7 Nm^3/kg TVS). The thermophilic range still shows its superior performances. The low SGP observed for Bassano dewatered sludge was due to the presence of bulking material (wood) in the sludge. After about 6 days the methane percentage reached a constant trend and an average of 70%.

Table. 4.: Characterisation of the inoculum and waste tested.

	T °C	Average SGP, Nm^3/kg TVS
Treviso	35	0,18 ± 0,03
Camposampiero	35	0,14 ± 0,02
Bassano	35	0,12 ± 0,01
Treviso	55	0,23 ± 0,01
Camposampiero	55	0,22 ± 0,02

Nielsen and Angelidaki (2008) analysed the residual methane potential of the effluents from about 20 anaerobic digester in Denmark, treating manure and other agro or food processing waste. They evaluated the loss of methane (as percentage) related to the methane production of the plant and found values in the range 5,9-24,8 %. These values were clearly related to the operationals conditions of the bioreactors: the higher the organic loading rate the higher percentage loss

3.3 DRI results

The tests were carried out only on dewatered sludge of the Treviso WWTP working at mesophilic temperature. Table 5 resumes the results of the four tests mentioned.

All the tests, both real and potential DRI, showed an index value under 1000 mgO_2/kgTVS h. It is therefore clear that the digestate is biologically stable in aerobic conditions (the index for good quality compost is some 1300 mgO_2/kgTVS h) and the time for a further stabilisation and reach of oxidative conditions is short (Drennan and Di Stefano, 2010).

Table. 5.: DRI test of Treviso dewatered sludge, parameters considered.

	Water holding capacity g H_2O/kg	Bulking agent	Density kg/l	TS g/kg	TVS g/kg	Kg of sample	DRI mg O_2/kg TVS*h
1 DRI-R		Yes	0,59	232	133	16,14	849
2 DRI-R		Yes	0,50	233	135	10,92	894
3 DRI-P	1183	Yes	0,46	192	112	12,13	905
4 DRI-P	1170	Yes	0,45	218	128	10,32	900

4. Conclusions

The experiments carried out allowed for some important considerations about the feasibility of the approach suggested:

- the thermophilic option can be considered as the best condition in co-digestion process of sludge and biowaste mixtures: improvements were in the range 45-50 % in terms of biogas yields;
- the dewatered sludge originated from the anaerobic digestion of WAS and OFMSW was tested with DRI and BMP tests. The digestate of Treviso WWTP showed a relatively low specific residual biogas production (0,23 m^3/kgTVS) and a DRI index under 1000 mgO_2/kgTVS h. The legal limit in Italy is fixed at an index value lower than 1300 mgO_2/kgTVS h.

The secondary treatment (by composting) of this substrate can be therefore avoided or performed in a very short time.

5. References

Adani, F., Lozzi, P., Genevini, P.L., Determination of biological stability by oxygen uptake on municipal solid waste and derived products *Compost Science and Utilization* **9** (29), (2001) 52–65.

Angelidaki I., Alves M., Bolzonella D., Borzacconi L., Guwy A.J., Kalyuzhnyi S., Jenicek P., Campos L., van Lier J.B. (2009). Defining the biomethane potential (BMP) of solid organic wastes and energy crops: a proposed protocol for batchassays. *Water Science and Technology* 59(5), 927-934.

Bolzonella D., Battistoni P., Susini C., Cecchi F. (2006). Anaerobic co-digestion of waste activated sludge and the OF-MSW: The experiences of Viareggio and Treviso plants (Italy). Water Science and Technology, 53(8), 203-211.

Bolzonella D., Pavan P., Battistoni P., Cecchi F. (2006) Anaerobic co-digestion of sludge with other organic wastes and phosphorous reclamation in BNR wastewater treatment plants. Water Science and Technology, 53(12), 177-186.

Drennan MF., Di Stefano TD. (2010) Characterization of the curing process from high-solids anaerobic digestion. Bioresources Technology, 101(2), pp. 537-544.

Mace S., Bolzonella D., Mata-Alvarez J., Cecchi F. (2003). Comparison of the biodegradability of the grey fraction of MSW of Barcelona in mesophilic and thermophilic conditions. *Water Science and Technology,* 48(4), 21-28.

Mladenovska, Z., Ahring, B.K., 2000. Growth kinetics of thermophilic Methanosarcina spp. isolated from full-scale biogas plants treating animal manure. FEMS Microbial Ecology 31, 225–229.

Nielsen H.B. and Angelidaki I., 2008. Codigestion of manure and industrial organi waste at centralized biogas plants: process imbalances and limitations. *Water Science and Technology* 58 (7) pp.1521-1528.