**Anaerobic digestion of bio-waste: a territorial and environmental friendly process. A review.**

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**Abstract**

Scientific and industrial experiences together with economical and policies changes of last 30 years, bring the Anaerobic Digestion among the most environmental friendly and economically advantageous technologies for organic waste treatment in Europe. Its diffusion took place around '90s, particularly in agricultural sector, when the centralised plant was becoming a territorial service. The opportunity of a territorial friendly approach, without barriers, where food wastes, the organic fraction of municipal solid waste, agricultural residues, waste from food processing plants, zoo-technical effluents, and other organic waste such as diapers, are co-treated, is not completely accepted but can be achieved through two strategies: one is the anaerobic digestion applied as a service for agricultural and farming sector, the other as a service for citizen (biowaste, diapers and wastewater treatment integration). The union of these two strategies is an environmental and territorial friendly process, aimed to produce renewable energy and fertilizer material, with a low green house gas emission and nutrients recovery. Moreover, the advantage of forthcoming application of AD even for added value row material production and new energy carriers must be taken into account.

Among several advantages of anaerobic digestion, the role of environmental controller was discussed, evaluating the ability of minimizing the impacts exploiting the biochemical equilibrium and sensibility as a quality assurance for digestate.

**Key words:** review, anaerobic digestion, biowaste, anaerobic co-digestion, integrated approach, energy recovery, biomethane, biohydrogen, nutrient recovery.

## 1.Introduction

The anaerobic digestion (AD) of solid biowaste has a strong scientific background since early ‘80s, in fact first papers in the literature dealing with AD of solid biowaste were published by a lot of authors such as Cooney et al., 1975, Diaz et al., 1977, Stenstrom et al., 1982, Fannin et al., 1984, Shmidell et al., 1986, Traverso et al., 1988, Cecchi et al., 1986, 1988(a,b), 1990(a,b,c,d). The first International Symposium on Anaerobic Digestion of Solid Wastes (ISAD-SW) held in Venice in 1992 (Special Issue of Water Science and Technology, edited by Cecchi et al., 1993), was the first and successful attempt of AD specialists aggregation (more than 40 countries represented and more than 200 delegates) and an important discussion opportunity about solid waste treatment. During these years there was an increasing concern about Municipal Solid Wastes (MSW) disposal, which was changing its waste-to-resource status, approaching to the new concept of separate waste collection. The conference outputs highlighted the importance of using Source Sorted-Organic Fraction of MSW or separately collected (SS-OFMSW, SC-OFMSW) which improves the AD’s yields and removal efficiencies (Wellinger et al., 1993, Battistoni et al., 1993, Owens and Chynoweth, 1993, Mata-Alvarez et al., 1993), the opportunity of composting the AD dewatered effluent for a good quality soil amendment production (Vallini et al., 1993, Engeli et al., 1993, Vermeulen et al., 1993), and the biological treatability of AD liquid effluent inside a waste water treatment plant (WWTP). This was the starting point of the concept that composting and anaerobic digestion are not competing technologies but synergic ones and WWTP should be part of a territorial approach for reclaiming material energy and nutrients, mainly phosphorous (Battistoni et al., 1997, 1998, 2000, 2001, 2005). During the second ISAD-SW held in Barcelona in 1999, others important aspects of AD process were deeply discussed, such as the positive energy balance of AD solid waste treatment (Edelmann et al., 2000), the reduction of fossil fuels utilization, the reduction of $CO_2$ emissions (Baldasano and Soriano, 2000) and the degradation of organic micropollutants and organochloride compounds. Global climate change and LCA started to be the focus of new research issues together with the fate of micropollutants, inorganic and organic ones. The organizing scientific committee summarized these outputs in a position paper together with a worldwide overview of AD (Verstraete et al, 2000) emphasizing that there must be an improved communication between various waste management sector and compost users, in order to guarantee a future of organic recycling. Hence, proper technology and land planning can upgrade the end product of digestion as a form of sequestered carbon: lower carbon footprint. The ISAD-SW conference took place again in 2002 in Munich and in 2005 in Copenhagen. In this last meeting, the anaerobic digestion of solid waste and energy crop (SW&EC) fusion was proposed and discussed during the IWA-AD Group meeting, addressing a strongly increasing of co-digestion of various substrates together with the request of a high quality end product. The concept of a territorial approach for AD process was born. ISAD-SW&EC was successful in its two editions in 2008 and 2011, held in Hammamet and Vienna respectively, where the widespread use of anaerobic digestion technology in agricultural sector was confirmed, pointing out the new issues related to the AD effluent final use (Nitrate Directive and quality control procedure) and nutrient removal/recovery (reclamation) technologies.

Today, the importance of AD process is irrefutable and counts over 13,800 biogas plants in Europe (in 2012) and more than 7,400 $MW_{el}$ of installed capacity (European Biogas Association, Biogas report 2012) providing following advantages: AD is suitable for stabilizing various organic substrates; a number of industrialised processes are available (mesophilic/thermophilic, dry/wet, CSTR/PF, etc.); renewable energy can replace fossil fuels (i.e. biomethane); AD effluent Nutrients can be recovery (specially phosphorus); digestate is suitable as fertilizer/amendment.

In Europe, even thanks to a strong Energetic policy support, Germany is the first country with 5,067 ktpe of biogas, produced mainly by decentralised agricultural plants, municipal waste methanisation plants and centralised co-digestion plants. United Kingdom and Italy, with 1,764 and 1,095 ktpe of biogas produced in 2012, are ranked second and third respectively but they still showed a higher percentage of biogas produced by landfill, mainly in UK. Compared with UK, the Italian agricultural sector was changed during last 15 years thanks to national incentives on renewable energy production and as a result of the European Nitrate Directive (91/676/EEC), increasing the number of decentralised agricultural plant, municipal waste methanisation plant and centralised co-digestion plant. Probably Italy, and the Veneto Region in particular, was the first European country where the industrial biowaste treatment plants were developed and was implemented the concept of co-digestion of sludge and biowaste (Cecchi et al., 1994, Pavan et al., 2000, Bolzonella et al., 2006). Spain then incorporated the concept, and outranked Italy in the application even thanks to European structural funds (Mata-Alvarez et al., 2000).

However, the overall vision of AD process implementation still has some gaps to be solved. In particular, the opportunity of a territorial approach, without barriers, where food wastes, the organic fraction of MSW, agricultural residues, waste from food processing plants and zoo-technical effluents, and other organic waste such as diapers, are co-treated, is not completely considered. That is, all the advantages linked with the application of the anaerobic digestion as an environmental and territorial friendly process, aimed to produce renewable energy and fertilizer material, with a low green house gas (GHG) emission and nutrients recovery, are still far to be fully exploited.

This gap is mainly due to controversial interpretation of legislation, both at national and European level, probably caused by an exceeding of precautionary principle application, (for example the debate on organics and inorganics micropollutants limits) but cultural limits could play a role. In fact, the AD process could overcome the toxicity problem thanks to its great sensibility to these toxic compounds, especially at thermophilic working temperature. It seems possible to speculate (literature is not so exhaustive) that, if the process is stable and well performing, digestate land utilisation automatically become feasible. That is the use of anaerobic digestion process as a controller for the environmental impact. Composting systems couldn't carry out this controller activity because the reactors, where the process takes place, are completely different. Composting takes place in piles with a low mixing degree, causing not homogeneous zones inside. These piles are improperly called "reactors", and in fact usually a proper process control is very difficult (i.e. the loss of water during oxidation process often causes a material dehydration (total solid contents over 30-40 gTS/kg) with a consequent possible shutdown of biological activity). A tentative of overpassing this problem is the adoption of long retention time (more than two months) to obtain a more or less homogeneous stabilized material. Different is the AD process, which takes place in completely mixed reactor that offers guaranties about homogenisation and toxic compound concentration. Hence different legislation have to be used for compost and digestate final disposal; in one process (composting) the control of the toxic compound level is obvious and necessary, while in the other (AD) is part of the process itself.

In agreement with these assumptions/assertions, in this paper two approaches were discussed aiming to evaluate the territorial application of the anaerobic co-digestion process: one approach is addressed to the primary production sector and the other approach to that of urban services focusing, in this case, to the technological issues that are the base of a proper process management and success. It will be developed the concept of AD process as the “environmental controller” emphasizing the limits of literature and reporting our laboratory and in the field experiences. Finally will be briefly indicated the paths toward which the anaerobic digestion process will move in the next future.

## 2. Two strategies to reach the environmental territorial sustainability

Anaerobic Co-Digestion of agricultural residues, energy crops, food industry residues and zoo-technical effluent is an attractive and widespread technology and is the most important example among the two proposed territorial approaches. Looking at the exponential diffusion of AD process at agricultural level, the AD technology should be considered a crucial integration of different actors needs, for example solving the necessity of stabilize organic matter produced from farming activities and to share land for fertilizer spreading achieving nitrate directive limits. The centralised form of AD, designed as a consortium of different users, can be an instrument for a territorial strategy. The second strategy regards the anaerobic digestion of biowaste and sewage sludge as a result of wastes and water treatments cycles integration. In that way the wastewater treatment plant became a territorial service for citizen, providing a new concept of treatment plant.

These two strategies can be even linked together in an overall view of a sustainable and environmental friendly approach and a service for society in terms of energy and material recovery.

### *2.1 The Anaerobic Digestion as a service for agricultural and farming sector*

Waste-to-bioenergy and waste-to-resources challenges were the driving force of biogas plant diffusion in Europe, attracting lots of interests and involving mainly the agricultural and farming sectors. In 1985 Danish Govern developed and implemented a demonstration program to show the potential of large-scale manure-based biogas plants. As reported by some authors (Angelidaki and Ellegaard, 2003, Raven et al., 2007) Denmark is known for its centralised biogas plant concept where a community of farmers cooperate in an organisation to supply and digest the manure in a centrally located biogas plant. Advantages of this approach were evident in fact it produced renewable energy, enabling the recycling of organic waste and reducing fertilizer use, with a consequent reduction of the greenhouse gas emission.

Usually the common substrates are livestock effluents such as pig or cattle slurry and manure that are available all over the year, then a codigestion approach is usually carried out using maize silage or similar cultivation. This is the typical rural approach. Avoiding food competition of energy crops harvesting for energy purpose, especially in Mediterranean areas, there are lots of available biomass and food-processing industry refuses suitable for bioenergy production. The seasonal availability of biomass, that can cover the whole year, assures a continue energy production, and opens the concept of a territorial service of anaerobic digestion. In fact food industry processes row material from agriculture such as tomatoes (Aug-Oct) to produce tomatoes sauces, or fruits (Aug-Dic) to produce juices, giving back to biogas plant the organic residuals (Figure 1).

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Livestock effluents | | | | | | | | | | | | |
| Winery wastes | | | | | | | | | | | | |
| Oil mill wates | | | | | | | | | | | | |
| Potatoes and onions | | | | | | | | | | | | |
| Apricot and peaches | | | | | | | | | | | | |
| Apples and pears | | | | | | | | | | | | |
| Maize | | | | | | | | | | | | |
| Tomatoes | | | | | | | | | | | | |

**Figure 1:** seasonal availability of agricultural residues and food processing wastes

For example, the feasibility of a centrally located anaerobic digestion facility, in the Mediterranean region, was successfully verified, co-treating slaughterhouse, olive mill and winery waste by Fountoulakis et al. (2008). Moreover Mediterranean regions substrates availability was evaluated by Petruccioli et al. (2013); these substrates and many others available, as those reported in figure 1, can be co treated in centralised plant. A study carried out by Zubaryeva et al. (2012) in a south Italy region, shows that the highest potential for electric energy production was estimated for OFMSW and olive oil cake, while the lowest potential is the one for cattle slurry and grape stalk, that must be co digested. Ward et al. (2008) reviewed the ways of AD optimisation of agricultural resources; among all, co-digestion studies have recognised ways of improving biogas yield and reducing HRT. These studies confirm the necessity of co-digest the crops biomass or plant biomass with ruminant manure, which contains high levels of organisms able to hydrolyse lingo-cellulose material.

In that way AD, and especially Co-digestion, became a territorial service for various substrates treatment, for energy recovery and for the production of soil amendment for agriculture, upgradable in a consortium feature.

### *2.2 The Anaerobic Digestion as a territorial service citizen*

The integration of the anaerobic digestion of biowaste and wastewater treatment, that is the co-digestion of sewage sludge and biowaste inside a wastewater treatment plant, is the approach proposed in 1994 by Cecchi et al. (1994) and implemented at full scale in 1999 as service for the Treviso City (North Italy) (Pavan et al., 2000). In that way the Biological Nutrient Removal (BNR) process efficiency was improved by adding the rapidly biodegradable matter coming from biowaste fermentation (this make easier the N and P biological removal), and was exploited the electric energy from biogas together with the phosphorous recovery from digestate by a crystallisation process (Battistoni et al., 1997, 1998, 2000, 2001, 2005). Digestate is usually sent to a composting plant to produce a high quality soil amendment. With this approach biowaste management became a resource, minimising the size of composting plant and allowing a better waste separation. Considering the case study of Treviso City (about 100,000 inhabitants), the approach can be extended to a larger area, the province of Treviso.

Treviso province (about 1 million of inhabitants) produces more than 100,000 ton per years of biowaste (60%) and green waste (40%): considering the availability of 1 composting plant treating about 35,000 t $y^{-1}$, and 1 anaerobic digestion plant treating 3,000 t $y^{-1}$ (the one of Treviso city), about 64,000 t $y^{-1}$ of biowaste+green waste have to be treated in plants located outside the province. For the specific case, this means that each ton of biowaste travels an average of 7.4 km .

Considering the wastewater treatment situation, Treviso province has 90 WWTPs, 15 of those with more than 10,000 PE of capacity and with an annual sludge production of 30,000 tons per years (20% of total solids content), with a prevision of 45,000 t $y^{-1}$ when fully implemented the sewage network.

Assuming to fully exploit the available volume of 5 existing AD plants (total volume of about 12,000 $m^3$), the whole province could use AD for organic waste and sludge treatment (organic loading applied of about 4 kgTVS $m^{-3}$ $d^{-1}$), with final composting of digestate and sludge, working in a synergistic way to produce renewable energy, avoiding cost of disposal and transport and lowering $CO_2$ emission. The electric energy and heat recovery prediction is illustrated in figure 2, supposing 1 million of inhabitants and adopting an integrated approach.

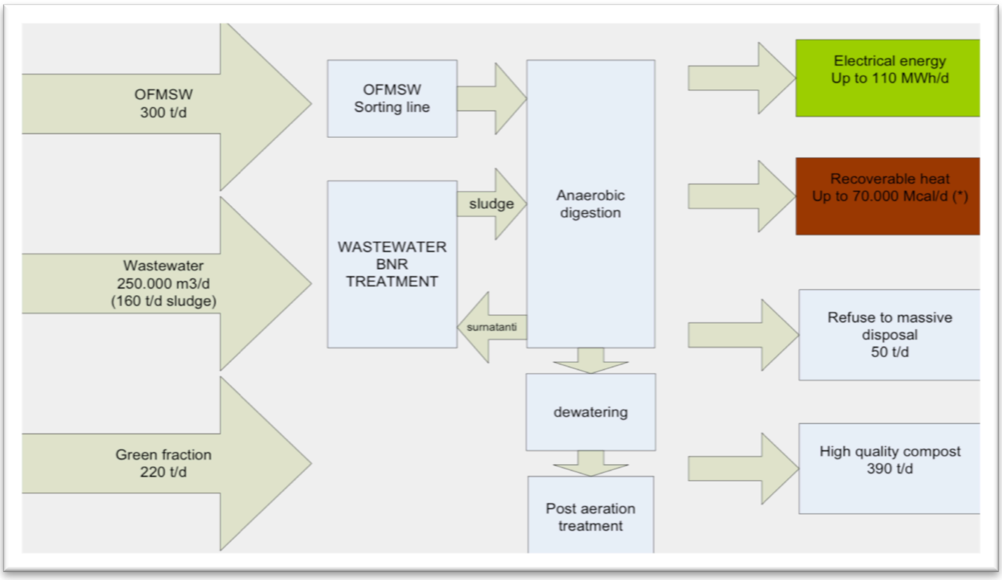


**Figure 2:** Flow scheme of the AD integrated approach of Treviso Province.

It is noticeable the advantage of AD exploiting as a territorial and friendly approach, in fact it is possible to recover up to 110 MWh $d^{-1}$ of electric energy and 390 t $d^{-1}$ of high quality compost, produced by the post aeration treatment of digestate and green waste.

### *2.2.1 Feedstock quality and availability: a facilities problem.*

From the process point of view almost all is known, studied and verified. In fact different technologies were developed, such as: wet/dry and semi-dry digestion; continuous and batch reactors; single phase and multi-phased; mesophilic and thermophilic working temperature; etc.

Implementing the Anaerobic Digestion in a biowaste treatment process, most of the problems are practical issues (plants' problem); hence simple, reliable and permanent solutions must be adopted in order to preserve the biological process and make management easier.

The importance of adopting an efficient separate collection system to obtain a high quality organic waste is as fundamental as for the valuable matter recovery (Hartmann et al., 2004). Door-to-door collection system gives the best quality characteristics in terms of inert material content and meets the quality requested for AD process. Obviously the organic waste obtained by mechanical selection must be forbidden. In fact, it can cause serious problems to plant facilities and can negatively affect the quality of end product and, moreover, usually require high-energy consumption for a proper selection (Cavinato et al., 2013). Nevertheless a mild mechanical separation of the OFMSW is suggested, even if the collection is a door-to-door system with a high quality of biodegradable matter. Another approach could be the under-sink disposer that assures the disposal of selected organic material (Bolzonella et al., 2003, Battistoni et al., 2007). Several pre-treatment technologies are available but three are the technologies widely used to mechanically sort OFMSW prior anaerobic digestion/codigestion treatments: wet pulper, extrusion press and wet sorting system. All these technologies have the same objective of improving biogas conversion through the size reduction, that allows a better microorganism contact, and inert material removal that can cause, in a long-term, the facilities consumption and/or accumulation inside the reactor. The functioning principles are reported here below putting together similar technologies.

*Extrusion press*: the waste is pushed inside the extrusion chamber under high pressure; in this condition the organic fraction is in part liquefied, passing through the extruder holes and the dry rejected fraction is discharged. Other pressure-based technologies are the use of a hammer mill coupled with a fixed screen–or screw press.

*Hydropulper*: after a first shredding step, biowaste is suspended in process water and disrupted for 0.5–1 h. After removal of the light fraction from the top and the heavy contaminated fraction such as glass, plastics, stones from the conical bottom of the hydropulper, the biowaste suspension is pumped into the anaerobic digester.

*Wet-refine system (Treviso)*: after a first shredding step the biowaste is sent to a mixer/separator where the dry matter content is lowered to 7–8% using sludge coming from WWTP, and the floating (upper part) and inert (bottom) materials are withdrawn.

These technologies are aimed to produce a material with low inert contaminant content, avoiding damage to piping and pumping systems (saving maintenance costs) and inert material accumulation inside the reactor (causing a reduction of working volume) and consequently a high organic material suitable for biogas conversion.

In Giuliano et al. (2011) three biowaste treatment plants in Europe were analysed in terms of biowaste pre-treatment efficiency before AD process. Mass balance, chemical physical parameters, waste classification and particle size distribution analysis were carried out on inlet substrates, rejected material and sorted waste. Among the results obtained, the particle size distribution after sorting steps gives interesting output. Fractions sizes were divided in three main categories: Coarse (more than 1 mm), Middle (from 0,25 to 1 mm) and Fine (less than 0,25 mm) fractions. Observing the Figure 3, different effects of pre-treatment systems were clear: coarse and middle fractions increase moving from wet pulper to wet selection, suggesting a more conservative approach of this last option.

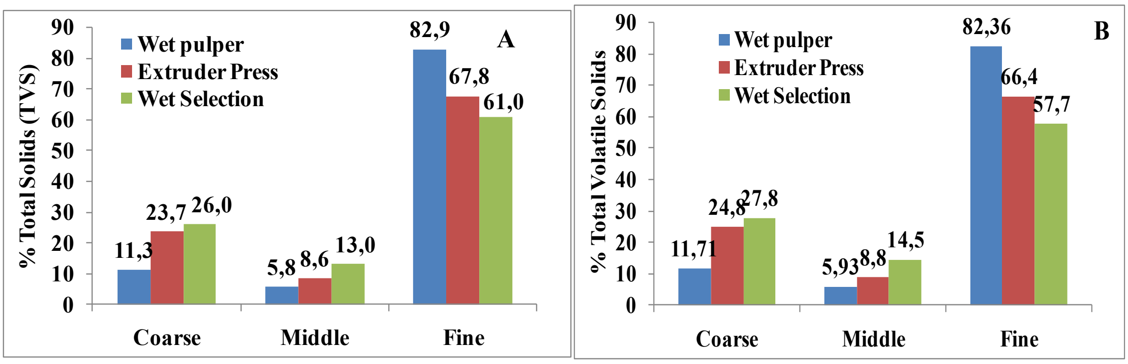


**Figure 3:** Total solid and total volatile solid content of three size particles obtained by three different pre-treatment technology.

This was confirmed by fine fractions trend, which has an opposite behaviour, showing the higher fines production associated to wet pulper, which was surely the more disrupting technique adopted. Hence wet pulper option lead to an output stream, which was richer in fines, at least 25 % more, than other technologies. Inert fines fractions were one of the causes of management problems in full-scale applications, due to pipes clogging, digester volume reduction, pump abrasion etc. Even if an higher organic material fragmentation probably lead to a higher kinetics of biological conversion in digesters, due to the higher surface/volume ratio of substrate, this advantage could be not enough to balance the amount of other negative effects coming from the heavy presence of inert fines fraction. It seems to be much more profitable to less reduce organics in size before digestion, demanding the degradation to the biological step of AD.

## 3. Anaerobic Digestion as environmental controller

To make possible a territorial friendly approach, first of all the European and Members States legislation must be reconsidered. In fact, the Waste Framework Directive (2008/98/EC) identifies bio-waste as "*biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants".* This definition does not include other organic materials reducing the possibility of exploiting all the advantage of an integrated and territorial approach. Moreover the Article 22 of Waste Directive says that "*the Commission shall carry out an assessment on the management of bio-waste that shall examine the opportunity of setting minimum requirements for bio-waste management and quality criteria for compost and digestate from bio-waste, in order to guarantee a high level of protection for human health and the environment."* Indicating the necessity of pointing out quality criteria, the legislation wrongly considers compost and digestate as the same thing. In fact, as reported in the premise, anaerobic digestion process take place in a CSTR, giving much more guaranties and effectiveness from several points of view if compared with composting, which can be surely part of a reclamation general strategy where post composting of digestate mixed with bulking agent produce a quality soil amendment (Vallini et al., 1993, Di Stefano et al., 2008).

Moreover the Member States policy differs a lot considering each local situation, for example only some States allow the co-treatment of biowaste and agricultural residues with the use of digestate as fertiliser, or allow the direct grid injection of biomethane.

The huge potentiality of Anaerobic Digestion must overcome these weaknesses and must include the scientific opinion for a new legislation based on environmental sustainability.

Anaerobic digestion can be the environment controller thanks to its low carbon impact, positive energy balance and, as a biological process, to its intrinsic property of being adaptable to most of organic substrates, obtaining in most of cases a material that respond to legislation limits of a quality soil amendment or fertilizer (Kupper et al., 2014). On the other hand this biological treatment is sensible to toxic amount of heavy metal, organic micro-pollutant etc. coming with the feeding, acting itself as a controller for the effluent quality. Speculating on this concept and considering the sensibility of AD microorganisms to some micro-contaminants, could be assumed that if the process fails at a specific concentration and this concentration is under the regulation limit, the biochemistry imbalance became the "warning bell" of a low quality effluent. Even if the complex biochemical system of AD biology suggests that with time acclimation can occurs, in literature are reported lots of research studies on AD inhibition (ammonia, pH, volatile fatty acids, salinity etc.) as reviewed by Chen et al. (2008), but few data about heavy metals or organics compounds toxic range are indicated, and often are really contrasting, based on specific case study. The wide range of concentrations is mainly due to different chemical-physical form assumed by heavy metals (precipitated as sulphide or hydroxides or carbonates, absorbed to solid fraction, biomass or inert fraction, or forming complex during AD), and the effective inhibition carried out by the soluble heavy metal form. Moreover, the solids content provide a protection from this inhibition and for this motif should be easier to compare data expressed as mg of metal per g of solid or volatile solid rather than mg per litre as usually used (Chen et al., 2008). In order to compare some toxic values reported in literature, in table 1 are indicated the limits of heavy metals of End of Waste proposal, expressed in milligrams of metal per litre assuming AD process with 25 and 35 gTS/l, and compared with toxicity limits (strong inhibition or 50% of biogas production reduction, $IC_{50}$).

**Table 1.** Comparison of EoW heavy metal limits and $IC_{50}$.

| | EoW 2014 | EoW 2014 | EoW 2014 | Parkin & Owen 1986 | Lo et al. 2012 | Fermoso et al. 2009 | Altas et al. 2009 | Lin& Shei 2008 | Yue et al.2007 |
|---|---|---|---|---|---|---|---|---|---|
| | mg/kg d.m. | mg/l @ 25 gTS/l | mg/l @ 35 gTS/l | Strong inhibition | $IC_{50}$ | $IC_{50}$ | $IC_{50}$ | $IC_{50}$ | $IC_{50}$ |
| Cu | 200,0 | 5 | 7 | 0,5 (sol) 50-70 | | | | 6,5 | 6,4 |
| Zn | 600,0 | 15 | 21 | 1,0 (sol) | 0,482 | | 7,5 | 4,5 | |
| Pb | 120,0 | 3 | 4,2 | | | | | | |
| Ni | 50,0 | 1,25 | 1,75 | 30 | 7,239 | 118 | 35 | | |
| Cr tot | 100,0 | 2,5 | 3,5 | Cr(VI) 3,0 (sol)200-250 Cr(III) 2,0 (sol), 180-420 | 0,124 | | 27 | 60 | 18 |
| Cd | 1,5 | 0,0375 | 0,0525 | | | | 36 | | 4,4 |

The values reported are in mg of metal per litre, so the TS content is not clear. But for some component, for example Zn, the toxicity values are below the limits. Comparison is difficult, but that could be an effective way to address the objective of EoW criteria on digestate, adopting the biology of AD as controller itself.

Moreover pathogens depletion is achievable especially at thermophilic working temperature.

In this contest, it seems clear that effluent quality is a hot issue from an environmental impact point of view, and there is still an open discussion about the necessity to have a positive list of input material in order to consider digestate usable as fertilizer or to set output limits. Recently the End-Of-Waste criteria (JRC, 2014) set some limits both on input material (avoiding sludge) and on digestate final quality, based on a European survey of about 25 AD samples of Biowaste, Manure+Biowaste, Manure+Energy Crops, suggesting concentration limits for heavy metals. In table 2, are reported the limits values of EoW proposal, Italian low on fertilizers (D.lgs 75/2010) and on agricultural sludge disposal (D.Lgs. 99/1992), and compared with experimental data considering the codigestion of biowaste alone, biowaste and sludge and winery waste mixed with sludge (Cavinato et al., 2014, Da Ros et al. 2014). Its possible to observe how the heavy metal content was respected for all the regulation limits, even with sludge addiction. The only value that is above the limit is Cupper, but this is linked with wine harvesting treatment process, and can give some suggestion on the amount of Winery waste treatable.

**Table 2.** Comparison of EoW and Italian limit values with heavy metal content in co-digestion effluents.

| | EoW 2014 | Italian regulation on fertilizers D.lgs 75/2010 | Italian regulation on use of sludge in agricolture D.Lgs 99/1992 | 37°C Biowaste Digestion | 37°C Biowaste and WAS co-digestion | 55°C Biowaste Digestion | 55°C Biowaste and WAS co-digestion | 37°C Winery waste and WAS co-digestion | 55°C Winery waste and WAS co-digestion |
|---|---|---|---|---|---|---|---|---|---|
| Cu mg/kg d.m. | 200,0 | 230,0 | 1000,0 | 68,1 | 138,0 | 52,5 | 105,8 | 929,0 | 927,0 |
| Zn mg/kg d.m. | 600,0 | 500,0 | 2500,0 | 155,0 | 452,0 | 129,0 | 352,0 | 1198,9 | 1120,7 |
| Pb mg/kg d.m. | 120,0 | 140,0 | 750,0 | 17,3 | 0,2 | 7,8 | 0,1 | 114,6 | 99,4 |
| Ni mg/kg d.m. | 50,0 | 100,0 | 300,0 | 42,1 | 17,4 | 27,0 | 23,5 | 25,8 | 24,2 |
| Cr tot mg/kg d.m. | 100,0 | 0,5 | | 85,9 | 34,8 | 51,5 | 29,4 | 48,4 | 42,7 |
| Cd mg/kg d.m. | 1,5 | 1,5 | 20,0 | 0,2 | 0,1 | 0,3 | 0,1 | 1,6 | 1,4 |
| Hg mg/kg d.m. | 1,0 | 1,5 | 10,0 | 0,2 | 0,1 | 0,1 | 0,1 | 0,4 | 0,3 |
| As mg/kg d.m. | 10,0 | | | 0,3 | 0,2 | 0,2 | 0,1 | | |

The analysis on digestate suggested by EoW, are aimed to develop a proper approach of digestate use considering among the objectives (enable disposal, reduce the dependence on land application, reduce the volume for lowering transport and disposal cost) to ensure more sustainable use of digestate products, to remove and recover substances and produce a customized fertilizer increasing digestate value, creating new markets for digestate products.

## 4. New Advanced view for treatment of biowaste

The waste management is often focused on treatment in order to meet the environmental legislation, but there are many research studies aimed to fully recover added value chemicals (bio-plastics) and energy (biohydrogen and biomethane).

### *3.1 Biomethane*

The advantage of biogas upgrading to methane (>90%) is the increased heating value and the consequent possibility of using it as automotive fuel or directly injected into the gas grid. There are several methods of biogas upgrading, such as physical absorption (pressurised water scrubbing, organic physical absorption), chemical absorption (ammine scrubbing), pressure swing adsorption, membrane treatment (gas-permeation) (Andriani et al. 2014, Petersson and Wellinger, 2009 ). Application of membrane technology is not widespread but seems to be the most adaptable to different plant configurations offering single o multiple stage approach and a multiple compressor variation (Sholtz et al, 2013, Basu et al. 2009).

### *3.2 Biohydrogen and Biohythane*

An advanced way of exploiting anaerobic digestion is the two-phase approach aimed to produce hydrogen gas in the first-phase (dark fermentation) and biogas in the second-phase (methanisation). These two gasses can be used separately or mixed in order to obtain bio-hythane, a gas mixture composed by 10% $H_2$, 30% of $CO_2$ and 60% of $CH_4$, that enhance combustion (better thermal efficiency and power output) and has reduced hydrocarbons emissions. The feasibility of biowaste treatment alone or co-digested with sludge was studied during last years (Cavinato et al. 2011a, 2011b, 2012, Chinellato et al. 2013, Giuliano et al. 2014) especially taking into account the sustainability of the process without external chemicals additions.

### *3.3 Bioplastics*

Volatile Fatty Acids (VFAs) are produced during the Acidogenic fermentation of anaerobic digestion metabolic pathway (Sans et al., 1995, Bolzonella et al., 2005). Adopting specific operative conditions (for example low HRT, pH range control, microorganism speciation) it is possible to produce VFA from a variety of organic wastes that can be used in several way such as the biological production of biodegradable plastics (Valentino et al. 2014, Lee et al., 2014). For example Polyhydroxyalkanoates (PHA) are biodegradable polymers that can be synthesized by microorganisms. The PHA content in accumulating microorganisms can be improved by optimizing the operational conditions of the cultivation reactor by feeding a specific VFA or solving critical factor for PHA accumulation (Mohan and Reddy, 2013). In that way it possible to achieve a PHA content of 40-77% using different substrate such as fermented food waste, fermented waste activated sludge, sugar cane molasses (Reddy and Mohan, 2012, Shen et al., 2014, Reis et al., 2011).

## Conclusions

Anaerobic digestion of bio-waste as a territorial and environmental friendly process can be achieved in the next future developing the following concepts:

- AD has to be considered as a territorial service both for agricultural and urban sectors: the centralised form of AD, designed as a consortium of different users, can be an instrument for a territorial strategy and, if located inside a wastewater treatment plant, it became a territorial service for citizen, providing a new concept of treatment plant;

- AD implementation for separate collected biowaste treatment must adopt simple, reliable and permanent solutions in order to preserve the biological process and make management easier;

- AD has a low carbon impact, positive energy balance and, as a biological process, has an intrinsic property of being adaptable to most of organic substrates, obtaining in most of cases a material that respond to legislation limits of a quality soil amendment;

- The sensibility of AD microorganisms to toxic amount of heavy metal, organic micro-pollutant etc. coming with the feeding, could be a feature to control the effluent quality;

- AD forthcoming technologies will allow to recover added value chemicals (bio-plastics) and energy (biohydrogen and biomethane).

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