

Anaerobic digestion and co-digestion of slaughterhouse wastes

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Abstract

The use of renewable energy is becoming increasingly necessary in order to address the global warming problem and, as a consequence, has become an high priority for many countries. Biomass is a clean and renewable energy source with growing potential to replace conventional fossil fuels. Among biomass, residual and waste ones represent a great resource for energy generation since they permit both to eliminate a possible waste and to produce energy. In the present work, the case of slaughterhouse wastes (SHWs) has been investigated. Anaerobic digestion is nowadays considered as one of the most important and sustainable conversion technology exploiting organic matter and biodegradable wastes. Biogas results from this bio-chemical process and mainly consists of methane and carbon dioxide, leading to produce thermal energy and/or electricity. In this paper, the European Regulations on animal by-products (ABPs) are described, and some previous study on anaerobic digestion and co-digestion of ABPs - more precisely SHWs - are considered and compared in order to fix a starting point for future tests on their co-digestion in a micro-scale pilot digester. This is to define optimal feed ratio values which ensure an increasing content of methane in the outgoing biogas.

Introduction

Renewable Energy Sources are increasingly used in order to reduce fossil fuels consumption and consequently those problems linked to global warming (N.L. Panwar *et al.*, 2011). Nowadays, biomass are one of the most widespread sources which can be efficiently used to produce energy in different ways (P. McKendry, 2002). Among them, Anaerobic Digestion (AD) is one of the most interesting energy conversion methods. It involves bacterial fermentation and permits the

organic matter decomposition in an oxygen free environment (A. J. Ward *et al.*, 2008). Biogas -primarily consisting of methane (40 - 70%) and carbon dioxide with traces of other gases- derives from AD process (T. Abbasi *et al.*, 2012).

AD leads to several applications and involve different categories of feedstock, *e.g.* industrial and municipal waste-waters, agricultural, municipal, food industry wastes and plant residues. An attractive subject is the possible use on Animal By-Products (ABPs) too (A.J. Ward *et al.*, 2008).

In the present paper, the European Regulations No 1069/2009 and No 142/2011 on ABPs are carefully described in order to identify which animal by-products can be used for biogas production. Furthermore several studies on SHWs anaerobic digestion and co-digestion have been considered and compared in order to fix a starting point for future laboratory tests. This plays a fundamental role if the slaughterhouse wastes produced in the Province of Viterbo have to be reused in a sustainable way by producing energy.

Current regulations on animal by-products

ABPs result from the slaughter of animals for human consumption, the production of dairy products, the disposal of dead animals and during disease control measures. Regardless of their origin, ABPs not intended for human consumption can determine a potential risk to public and animal health and to the environment. The disposal of all ABPs could lead to unbearable costs and risks for the environment which consequently need to be reduced. This problem might be successfully overcome by producing energy with ABPs in a sustainable way. (Regulation EC No 1069, 2009).

The Regulation (EC) No 1069/2009 of the European Parliament and of the Council lays down health rules with specific regard to ABPs and derived products not intended for human consumption. According to the law, ABPs are distinguished in three categories, depending upon the risk they pose towards human, animals and environment, and establishes their potential application (Table 1). Furthermore the corresponding treatments and uses for the treated ABPs categories are defined (Bayr *et al.*, 2012a).

According to the above-mentioned regulation, the use in AD plants is allowed for Category 2 after or without pressure sterilisation – depending on the type of ABPs - and Category 3. For “pressure sterilisation” it is meant the processing of ABPs, after reduction in particle size smaller than 50 mm, to a minimum temperature of 133°C for at least 20 minutes and at an absolute pressure of at least 3 bar (Regulation EC No 1069/2009).

Actually in the Commission Regulation (EU) No 142/2011, implementing Regulation (EC) No 1069/2009, some uses for biogas production are considered for those products derived from processing materials belonging to Category 1. In more detail, the latter products could be transformed into biogas; nevertheless, the digestion residues must be disposed by incineration or co-incineration, as Category 1 materials. If Category 1 materials are subjected to Alkaline hydrolysis pre-treatment, they could be transformed in a biogas plant and subsequently combusted

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rapidly at a minimum of 900°C, followed by rapid chilling (quenching), but the transformation shall take place on the same site as the processing and in a closed system. Additionally in the case of high pressure hydrolysis pre-treatment, the product derived from Category 1 material could be used for biogas production, but the whole process must take place on the same site and in a closed system; the biogas produced must be combusted rapidly in the same plant as above explained for the alkaline hydrolysis case. Whereas the products derived from Category 2 and 3 processing can be used for biogas production without restrictions (Commission Regulation (EU) no 142, 2011).

According to Commission Regulation (EU) no 142/2011, a biogas plant must be equipped with a pasteurisation/hygiene unit, which cannot be by-passed for ABPs or derived products introduced with a maximum particle size of 12 mm before coming into the unit. Nevertheless this unit is not mandatory if the ABPs are processed with the pre-treatments indicated in the Regulation for the specific categories and for some particular ABPs belonging to Category 2 and 3. In Table 2 some pre-treatments are reported.

Anaerobic digestion of SHWs

As indicated in EC 1069/2009, AD represents a treating possibility for ABPs, in order to decrease the environmental impact and to produce energy from biogas for local uses. In this sense, AD is considered an interesting alternative for waste management (Banks and Wang, 1999). Furthermore, digestion effluents can be used as fertilizers in agriculture (Mata-Alvarez *et al.*, 2000; Salminen *et al.*, 2001; Zhang and Banks, 2012).

SHWs represent potentially an excellent substrate for anaerobic digestion because of their high content of lipids and proteins (Heinfelt

and Angelidaki, 2009). However, different studies have proved that the AD of these wastes is practicable only for low organic loading rate (OLR) and hydraulic retention time (HRT) (Salminen and Rintala, 2002) and is particularly prone to failure because of the production of inhibitory compounds: ammonia, volatile fatty acids (VFAs) and long chain fatty acids (LCFAs) (Salminen and Rintala, 2002a; Bayr *et al.*, 2012b; Heinfelt and Angelidaki, 2009; Edstrom *et al.*, 2003; Masse *et al.*, 2002; Broughton *et al.*, 1998; Lokshina *et al.*, 2003).

Co-digestion of SHWs with other biomass, containing low content of nitrogen and/or lipids, permits to improve the process stability and methane production (Bayr *et al.*, 2012a; Salminen *et al.*, 2003; Rosenwinkel and Meyer, 1999).

A two-phase digestion system might represent an alternative solution leading to increase process efficiency, solid reduction, chemical oxygen demand (COD) removal and conversion in biogas (Wang and Banks, 2003; Banks and Wang, 1999).

Several tests were carried out in order to obtain a profitable AD process for biogas production. Thus, evaluations on different parameters variation were investigated as follows: pressure and temperature increases in AD processes or in pre-treatments, but without good results (Cuestos *et al.*, 2010); an increase of lipids or a change of the bacterial community structure, with discrete results (Palatsi *et al.*, 2011). Other studies evaluated the saponification of lipids in SHWs during pre-treatments and the use of ethanol biodegradation: a biogas improvement and, in some cases, the kinetic reactions were shown. However, the results are not enough clear to ensure the success of the process (Battimelli *et al.*, 2009; Battimelli *et al.*, 2010). Other studies concern the effects of influent flow rate variation on biogas production improvement both in BATCH anaerobic digesters (Resch *et al.*, 2006) and in continuously stirred tank reactors (CSTRs) (Marcos *et al.*, 2012).

Table 1. ABPs classification and allowed uses for biogas production according to Regulation (EC) No 1069/2009 of the European Parliament

Category	Animal by-products	Biogas production
1	All body parts of the following animals: suspected of being infected by a TSE; pet, zoo and circus animals; animals used for experiments; wild animals if suspected of being infected with diseases communicable to humans or animals; contained specified risk material. ABPs derived from animals submitted to illegal treatments or containing residues of other substances and environmental contaminants. ABPs collected during waste-water treatments of plants processing Category 1 material or risk material. Catering wastes from means of transport operating internationally. Mixture of Category 1 with Category 2 or 3 material	Not allowed. Allowed after specific pre-treatments, but provided the digestion residues are disposed of by incineration and co-incineration
2	Manure and digestive tract content; ABPs collected during waste-water treatments of plants processing Category 2 material or from slaughterhouses. ABPs containing residues of authorised substances. ABPs declared unfit for human consumption due to the presence of foreign bodies. ABPs imported from a third country and fail to comply with Community veterinary legislation. Animals or parts (different than Category 1 and 3) that slaughtered or killed other than for human consumption, fetuses, oocytes, embryos and semen not for breeding purposes; dead-in-shell poultry. Mixture of Category 2 with 3 material. ABPs other than Category 1 or 3	Allowed after pressure sterilisation or in biogas plant with pasteurisation and hygienisation unit. Allowed without pre-treatments only for specific ABPs of this Category
3	Carcases and parts of animals slaughtered or, in the case of game, fit for human consumption but not intended for this use for commercial reasons. Carcasses and the following parts of animal slaughtered or game killed for human consumption: parts unfit for human consumption according to Community legislation, heads of poultry, hides, skins, horns, feet, pig bristles, feathers. ABPs from poultry or lagomorphs slaughtered on the farm. Bloods of animals slaughtered in a slaughterhouse and considered fit for human consumption. ABPs arising from the production of products intended for human consumption. Products of animal origin, foodstuffs, pet food or feeding stuffs, no longer intended for human or animal consumption for commercial reasons. Blood, placenta, wool, feathers, hair, horns, hoof cuts and raw milk, aquatic animals, ABPs from aquatic animals. Eggs, egg by products, including egg shells. Adipose tissue from animals slaughtered in a slaughterhouse. Catering wastes	Allowed after pre-treatments 1 to 6 or 7 or in a plant with pasteurisation and hygienisation unit. Allowed without pre-treatments for specific ABPs if authorised by the competent authority

Mono and co-digestion of pig, poultry and cattle SHWs

Several studies reports experiments on AD of pig SHWs. Tests in BATCH reactor - at 35°C - measured the following methane productions: 428 dm³CH₄/kgVS (Bayr *et al.*, 2012a) and 580 dm³CH₄/kgVS (Rodriguez-Abalde *et al.*, 2011). Methane potentials of 225-619 dm³CH₄/kgVS were evidenced on different pig wastes - meat, bone flour, fat, blood, hair, meat, ribs, raw wastes - at 37 and 55°C in BATCH reactor (Hejnfelt and Angelidaki, 2009).

Experiment results on anaerobic mono-digestion in Continuously Stirred Tank Reactor (CSTR) are not attended, but tests on co-digestion shows the following results: five fractions of rendering wastes with poultry, cattle, pig slaughterhouse wastes with a methane production of 717 dm³CH₄/kgVS at 35°C (Bayr *et al.*, 2012a); pig mixed SHWs with solid pig manure have a methane yield of 489 dm³CH₄/kgVS at 37°C (Hejnfelt and Angelidaki, 2009).

Experiments on mono-digestion of poultry SHWs in BATCH reactor shows a methane yield of 262-266 dm³CH₄/kgVS at 35°C (Bayr *et al.*, 2012a). Whereas tests in CSTRs evidences a methane production of 520-550 dm³CH₄/kgVS at 35°C (Salminen and Rintala, 2002) and 600-700 dm³CH₄/kgVS at 34°C (Cuestos *et al.*, 2008). The firsts values are obtained under mesophilic conditions in 2 dm³ CSTR operating with 0.8 kgVS/m³d with an HRT of 50 days.

A study on co-digestion of poultry SHWs with Organic Fraction of Municipal Solid Wastes (OFMSWs) - at 34°C, in CSTR - reveals a methane potential of 400-500 dm³CH₄/kg VS.

A methane yield of 460 dm³CH₄/kgVS is reported for poultry waste at 35°C (Rodriguez-Abalde *et al.*, 2011) and higher potential is obtained for offal: 210-910 dm³CH₄/kgVS at 35 and 55°C (Salminen *et al.*, 2003).

Experiments on mono-digestion of bovine SHWs in BATCH reactor shows a methane yield of 572 dm³CH₄/kgVS at 35°C (Bayr *et al.*, 2012a).

Methane yield of 270-350 dm³CH₄/kgVS have been measured during co-digestion of solid cattle and swine SHWs with fruit/vegetable wastes and solid cattle/swine manure; the test were carried out in mesophilic

conditions (35°C) in a CRST and showed that digestion with mixed substrates is better than with single substrates (Alvarez and Liden, 2008).

Methane yield of 400-500 dm³CH₄/kgVS has been measured during co-digestion of Poultry SHWs with organic fraction of municipal solid waste (OFMSW); the test were carried out in mesophilic conditions (34°C) in a CRST (Cuestos *et al.*, 2008; 2009; 2010). At the beginning of study carried out in 2008, initial problems with accumulation of digestion intermediates occurred, but after an acclimation at low organic loading the mixture could be treated. A dilution of slaughterhouse material with fresh water was used in order to reduce the ammonia concentration.

Methane yield of 400-430 dm³CH₄/kgVS have been measured during co-digestion of ABPs from meat processing industry with sewage sludge; the test were carried out in mesophilic conditions (35°C) in a CRST (Luste and Luostarinen, 2010).

Co-digestion of manure and rumen (Rosenwinkel and Mayer, 1999) and blood and rumen from cattle and pigs were studied in laboratory in a pilot-scale plant at 37°C and with heating pre-treatments (Edstrom *et al.*, 2003).

A study using fruit and vegetable wastes to improve the nutrient balance in sequencing batch anaerobic digestion was carried out by Bouallagui *et al.* (Bouallagui *et al.*, 2009).

Pitk *et al.* studied methane potential of category 2 and 3 SHWs rendering products: melt, decanter sludge, meat and bone meal, technical fat and flotation sludge from wastewater treatments; values in the range 390-978 dm³CH₄/kgVS were measured (Pitk *et al.*, 2012).

Pre-treatments effects on AD

Several studies evaluated the difference between the biogas production starting from treated and un-treated SHWs.

Some studies were carried out in batch reactor, at 55°C, and on different pig SHWs - meat, bone flour, fat, blood, hair, meat, ribs, raw

Table 2. Some of pre-treatments for ABPs before using in anaerobic digestion plants (Commission Regulation (EU) No 142, 2011)

Category	Uses in biogas plants	Treatments
1-2-3	Standard treatment 1: pressure sterilisation	Particles size ≤ 50 mm; T ≥ 133°C and pressure (absolute) ≥ 3 bar for at least 20 minutes
1-2-3	Standard treatment 2	Particles size ≤ 150 mm; T ≥ 100°C for at least 125 minutes, T ≥ 110°C for at least 120 minutes, T ≥ 120°C for at least 50 minutes
1-2-3	Standard treatment 3	Particles size ≤ 30 mm; T ≥ 100°C for at least 95 minutes, T ≥ 110°C for at least 55 minutes, T ≥ 120°C for at least 13 minutes
1-2-3	Standard treatment 4	Particles size ≤ 30 mm must be placed in a vessel with added fat: T ≥ 100°C for at least 16 minutes, T ≥ 110°C for at least 13 minutes, T ≥ 120°C for at least 3 minutes
1-2-3	Standard treatment 5	Particles size ≤ 20 mm must be heated until they coagulate and then pressed so that fat and water are removed from the proteinaceous material. The latter must then be heated: T ≥ 80°C for at least 120 minutes, T ≥ 100°C for at least 60 minutes
3	Standard treatment 6	Specific treatment for Category 3 animal by-products originating from aquatic animal or aquatic invertebrates only
3	Standard treatment 7	Other processing method authorised by the competent authority
1-2-3	Alternative treatments Alkaline hydrolysis process	Materials resulting from processing may be transformed in a biogas plant and subsequently combusted rapidly at a minimum of 900°C, followed by rapid chilling ('quenching'); for Category 1, the transformation into biogas shall take place on the same site as the processing and in a closed system;
1-2-3	Alternative treatment: High pressure hydrolysis biogas process After standard method 1.	In the case of starting material of Category 1, the entire process must take place on the same site and in a closed system and the biogas produced during the process must be combusted rapidly in the same plant at a minimum of 900 °C followed by rapid chilling (quenching)

wastes - subjected to the following treatments according to the European Regulation: pasteurization at 70°C for 1 hours, sodium alkali hydrolysis (50 or 100 g NaOH/kgVS), sterilization at 133°C and 300 kPa for 20 minutes; the results show that pre-treatments had no effect on methane yields (Hejnfelt and Angelidaki, 2009).

A methane potential of 351-381 dm³CH₄/kgVS was determined at 35°C, for AD of meat and bone meat (Wu *et al.*, 2009).

Conversely other studies show some effects of pre-treatments on AD. A potential biogas yield of 1.14 l biogas/gVS is measured for pasteurised SHWs (1 hour at 70°C) is shown, whereas for un-pasteurised ones it is 0.31 l biogas/g VS (the production is about fourfold in the pasteurised case) (Edstrom *et al.*, 2003). A growth in methane potential of about 14-18% is shown for the same pre-treatment with particle sizes lesser than 12 mm and applied to mixture of daily manure and biowastes and in mesophilic conditions (Paavola *et al.*, 2006).

Several pre-treatments were investigated in order to reduce the particle sizes and to promote the lipids solubilisation. An increase of hydrolysis rate was achieved through the following pre-treatments:

- saponification at different temperatures - 60, 120 and 150°C - for 30 minutes and AD tests in mesophilic and thermophilic conditions in batch reactor and on fatty SHWs; the best performances were observed for the treatment at 120 °C (Battimelli *et al.*, 2009;2010);
- enzymatic hydrolysis (Masse *et al.*, 2003)
- enzymatic bio-augmentation (Cirne *et al.*, 2006).

In order to prevent the LCFA inhibition some treatments were studied, such as the use of acclimated biomass (Cavaliere *et al.*, 2008), the supplement of adsorbent (biofibers or bentonite) (Palatsi *et al.*, 2009), the use of feeding strategies with sequential LCFA accumulation-degradation steps (Cavaleiro *et al.*, 2009).

Affes *et al.* evaluated different configurations for anaerobic monodigestion for fat from cattle carcasses in mesophilic conditions (35°C). The system combines saponification wastes pre-treatments, AD in CSTR and solid recirculation. The studies are carried out with/without waste saponification pre-treatments (at 70°C for 60 minutes) and with/without digestate solid fraction recirculation. An enhancement on methane yield and COD degradation efficiency was achieved; the best performance was obtained in the reactor equipped with pre-treatments and recirculation. Indeed saponification enhances the emulsification and bioavailability of solid fatty residues, whereas recirculation minimizes the substrate wash out and induces the microbial community adaption to the treatment of the lipid/LCFA based substrates (Affes *et al.*, 2013).

Conclusions

The European Regulations describe carefully which SHWs could be used in AD plants and establishes potential applications without any restriction for category 3 only. As for category 2, some restrictions must be applied, whereas with regard to category 1 the use for biogas production is exceptional, complicated and permitted after specific pre-treatments only.

The analysis of different studies on AD of SHWs have shown that a good conclusion of the process can be achieved in mesophilic conditions, whereas it is considerably complicated in thermophilic conditions.

Furthermore co-digestion with other substrates determines better results than mono-digestion of SHWs.

As for pre-treatments effects on AD process, the results are debatable, since pre-treatments influence the biogas production yield according to some authors, whereas other authors demonstrate no effects on the process.

In order to exploit local SHWs by generating energy, future studies will concern co-digestion laboratory tests with different co-substrates. Nowadays, with specific regard to the Province of Viterbo, the following data on SHWs production are available: 2624,1 ton for cattle, 285,7 ton for pigs and 2167,5 ton for ovine and caprine (ISTAT, IZS).

The expected results will help to correctly size digesters in the Province of Viterbo.

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