ANAEROBIC DIGESTION OF MUNICIPAL SOLID WASTE, BIOWASTE & COMMERCIAL WASTES - EXAMPLES OF: 1) SUCCESSFUL REVAMPING OF EXISTING PLANTS 2) CO-DIGESTION OF BIOWASTE AND COMMERCIAL WASTE WITH AGRICULTURAL RESIDUES

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ABSTRACT: Anaerobic digestion (A.D.) of the organic fraction of municipal solid waste (MSW), Biowaste and Commercial waste combines the reduction of waste to be landfilled with the production of fertilizer and renewable energy, generating electrical and thermal energy by the valorization of the generated biogas. Thus, an A.D. plant can provide environmental, economical and social benefits. In case of co-digestion with other biomasses (such as manure and agricultural substrates) further economical and process benefits can be achieved. Unfortunately waste contains impurities that, if not efficiently removed, cause to the plant heavy biological and mechanical-hydraulic problems. Ecoparc 1 plant in Barcelona was started in 2001 and was planned to treat 300.000 t/a (250.000 t/y of MSW and 50.000 t/y of organic fraction from MSW). Mainly because of insufficient elimination of contaminant upstream, the plant never reached the expected treatment capacity, suffering high solid sedimentation in digester, pump clogging, low biogas production and high fraction to be landfilled. Biotec successfully revamped the plant by applying BTA® Hydromechanical pre treatment. Similar results have been achieved with the revamping of Cà del Bue in Verona Italy and Burgos in Spain. Castelleone -IT- co-digestion plant started in 2010 and is authorized to treat 100.000 t/y (20.000 t/y of biowaste, 6.000 t/y of commercial residues, 6.000 t/y of agricultural substrates and 68.000 t/y of manure), generating 1.676 kWel and producing approx. 100.000 t/y of digestate, successfully used as fertilizer after proper sanitation. In this paper the above mentioned plants are presented.

Keywords: select waste; anaerobic digestion; biogas; digestion;renewable energies.

1 INTRODUCTION

Anaerobic digestion (A.D.) of the organic fraction of municipal solid waste (MSW), Biowaste and Commercial waste combines the reduction of waste to be landfilled with the generation of renewable energy, producing electrical - thermal energy by the valorization of the generated biogas and the production of digestate, which can be used directly as fertilizer or aerobically stabilized in order to obtain high value compost. Thus, an A.D. plant can provide environmental, economical and social benefits.

Co-digestion is the simultaneous digestion of a mixture of two or more substrates [1] Usually, co-digestion improves the biogas yields from anaerobic digester due to positive synergisms established in the digestion medium and to the supply of possible missing nutrients by the co-substrates [2].
Co-digestion of biowaste or commercial residues with agricultural residues gives the following benefits to the stakeholders:

- to the farmers: the possibility to improve the profitability of their biogas plants and a source for free fertilizers;
- to the waste treatment companies: a location where a waste treatment plant will be accepted and the link to the end-user of the fertilizer/digestate produced in the plant;
- to the authorities/community: a good location for a waste treatment plant and the certainty that the digestate produced will be recycled as fertilizer. Thus, it's likely that the plant will be effectively well managed and optimized as local farmers are directly involved and interested in good plant performances. The optimization of the overall environmental impact combining management of waste, manure and fertilizer in a single plant equipped with a pipe network for manure and fertilizer handling without the need of road transportation.

For the co-processing of these streams in agricultural biogas plants, the efficient removal of the impurities contained in the residues is essential to guarantee a high reliability of the anaerobic digestion process and to meet not only the quality criteria fixed in the environmental laws, but also the quality requirements of the farmers owning the plant taking care their land where the digestate is spread.

Nowadays in Europe more than 6 million tons of MSW, Biowaste and Commercial waste are treated in more than 200 full-scale plants working with different technological configurations (dry or wet systems working under mesophilic or thermophilic conditions). Unfortunately, if compared to clean biomasses generally fed in A.D plants (such manure, maize etc.), waste is harder to be processed and can cause different operational problems, both biological (such as toxic element contamination) and mechanical-hydraulic (digester, pumps and pipe clogging, wear etc). In fact, due to poor planning, design or bad operation (considering in particular the pre-treatment phase), not all plants are been equally successful, causing environmental, economical and social problems.

2 BTA® Hydromechanical Pre-treatment

In order to guarantee high plant performance and availability, BTA developed along the years a high efficiently pretreatment: the BTA® Hydromechanical Pre-treatment, which consists of two main steps:

- **BTA® Waste Pulper** is a wet pretreatment system working in batch load. Feedstock is added to pre-filled process water into the BTA® Waste Pulper. A

mixer generates a vigorous turbulence which promotes a very selective modification of the waste fed: only non-soluble organic components are reduced to fibers by hydraulic shearing forces and brought into suspension. During this first step, in the BTA® Waste Pulper the digestible organics are defibered and dissolved, the organic suspension obtained is pumped through an internal sieve with 10 mm mesh size toward the GRS.
After suspension extraction, process water is added to dilute and wash contaminants bigger than 10 mm remained within the Pulper. In this way, it's created a low viscosity medium that facilitates a further impurities removal as heavy materials (density > 1 t/m^3) settle and light materials float. Thus, there are three streams outcoming from BTA® Waste Pulper: raw organic suspension; light fraction (plastics, foils, textiles, wood, etc.) and heavy fraction (stones, bones, batteries, core fruits etc.). Both light and heavy fractions are flushed and washed with recirculated process water.

The suspension still contains sand, glass, shellfish, egg, shell pieces and similar smaller than 10 mm which must be removed in order to avoid the above described problematic, such as equipment wear, pipe clogging and settling inside the digester.

- **BTA® Grit Removal System (GRS):** the grit fraction is efficiently removed in the BTA® Grit Removal System (GRS), which basically consists in a storage tank, a hydro-cyclone, a classifying screw and a grit box. Grit-enriched sludge is discharged by the hydro-cyclone´s centrifugal forces as underflow into the classifying tube, where it sediments in the grit box placed below. Simultaneously, the content of organic particles in the grit is reduced by elutriation. The separated impurities are discharged in intervals from the grit box to a classifying screw downstream, where the smallest organic particles are removed and the grit is dewatered and collected in a container. The organic suspension, free from contaminants, is pumped to the buffer reactor, which ensures a following constant feeding of the A.D. reactor.

Due to its peculiar high efficience selective removal, BTA® Hydromechanical Pre-treatment allows to feed directly inside the pulper the commercial residues with their packaging. In fact the inert material characterizing the packaging (such as glass, plastic, wood) are removed material while the organic content is converted in biogas inside the digesters.

All the BTA® Hydromechanical Pre-treatment is accomplished with recirculated process water taking advantage from waste water content: part of the digestate is dewatered and merged with water coming from the Hydromechanical Pre-treatment (light fraction, heavy fraction and sand dewatering), filtered, and re-used for the BTA® Waste Pulper and plant's purposes.

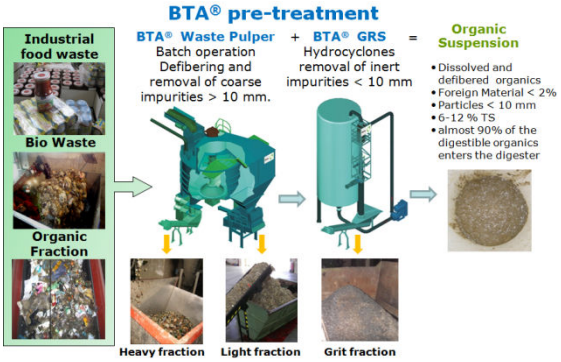

Figure 1. *BTA pretreatment scheme*.

3 REFURBISHMENT OF EXISTING PLANTS – VERONA AND ECOPARC

The importance of a high efficiency of the removal of the non-digestible material will be explained on the cases of the MBT plants in Ca'del Bue, Verona (Italy) and Ecoparc 1, Barcelona (Spain). In both cases problems emerged in the digestion step just shortly after the hot start-up. The reason was an inefficient separation of contaminants which led to the formation of distinct scum layers and massive sediments in the bioreactors, as well as constantly blocked pipes.

On the other side, a low degree of selectivity in the separation of the domestic waste fraction resulted in a too small input of organic substance into the digestion and therefore in a lower biogas production than expected. At the same time, the high amount of organics in the rejects not only led to an unacceptable quality of them, but to an increased amount of rejects to be landfilled.
In both cases BTA and its partner and licensee Biotec Sistemi S.r.l. were commissioned to replace the existing wet mechanical pre-treatments by the BTA® Hydromechanical Pre-treatment (as described in 3.2).

3.1 Verona revamping

After refurbishment, the MBT Ca'del Bue was put into operation again in 2002 and was in operation till 2006, when the plant was shut down due to problems in the incineration part of the plant. During these years, an availability of the pre-treatment and anaerobic digestion process between 90 to 95% could be demonstrated. Furthermore, independently of the strong fluctuations in the waste composition, a high quality in the cleaned organic suspension going to the digestion was ensured, while the loss of digestible organics through the removed light, heavy and grit fraction was limited to less than 3%.

3.2 Ecoparc 1 revamping

The plant of Ecoparc 1, one of the currently 17 digestion plants in Spain with domestic waste fractions input, has been designed to process 300.000 t per year: 250.000 t of residual waste and 50.000 t of organic waste, of the city of Barcelona.

Linde KCA was awarded the contract to build the plant. Start-up took place in 2001; during six years operation the facility did not achieve the design performances: low yearly capacity (average 170.000 t/y), very low amount of recovered materials, very high percentage of reject materials (average 64,4%), high

content of (more than 15%) easily degradadable organic material in the rejects [3].

Basically the inefficient separation of contaminants compromised the recovery of recyclable materials (biogas, compost), increased heavily the amount of reject material and caused frequent problems in the plant lines as well as scum layers and massive sediments in the bioreactors with consequent need to frequently empty the digesters.

Biotec was commissioned by UTE Ecoparc to revamp the wet mechanical processing according to the BTA process in December 2006 after a long and deep evaluation of the proposed technology and of similar BTA reference plant. The consultants of the Municipality of Barcellona, who are controlling and evaluating since years the operating results of the three waste anaerobic digestion plants of the city, supported the choice of the BTA process. The revamping included the delivery of:

- the whole wet-mechanical processing, consisting of N°3 32 m^3 BTA Waste Pulpers, N°4 BTA® Grit Removal Systems as well as thickeners, pumps, process water circuit, accessories and automation
- the revamping of one of the four 6.000 m^3 digesters in accordance to BTA guidelines.

Figure 2: *BTA® Hydromechanical Pre-treatment in Ecoparc I, Barcelona*

The anaerobic digestion line in the Ecoparc I in Barcelona was restarted in 2008 and has successfully been in operation since then, treating approx. 50.000 ton waste/year.

The Plant Owner and the Municipality are very satisfied with the plant after almost four years operation as it has operated profitably and successfully in terms of performances and availability:

- Pretreatment efficiency: the organic suspension produced and fed to the anaerobic digestion is almost free from contaminants (inerts in the suspension < 0,7%, over 98% of which are < 1mm) and has constant characteristics independently from plant feed fluctuations, the rejects have a very low content of organic material degradable under anaerobic conditions (< 10% on dry matter basis) thus allowing reduced costs for landfill disposal;

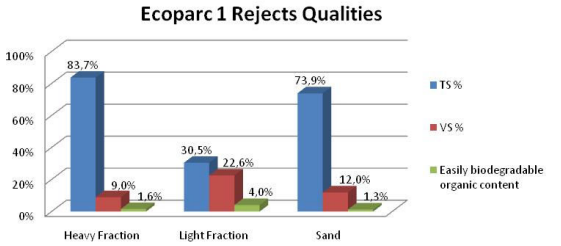

Figure 3: *Ecoparc 1 rejects quality*

- high anaerobic digestion performances with a high degradation of organic suspension, a higher specific biogas production related to the input to the wet pre-treatment. Biogas and energy production resulted to be : 152 m^3/t_{IN} in 2010, 154 m^3/t_{IN} and 369 kWh/t_{IN} in 2011
- availability of anaerobic digestion; the plant is in operation since more than three years and the digester had an availability of 100% with no need of any maintenance;
- low consumption of electric energy in the hydromechanical pre-pretreatment (approx. 32 kWh/t).

These examples show the importance of an effective removal of impurities before the anaerobic digestion of the organic waste fraction in order to avoid problems in the digestion step and guarantee a high process reliability.

Despite these two examples being wet digestions it must be pointed out that similar problematics have also been observed in dry digestion systems and that operators from these systems as well have been evaluating the options to improve the efficiency of the removal of impurities upfront the digestion.

4 CO-DIGESTION PLANT OF CASTELLEONE REFURBISHMENT OF EXISTING PLANTS – VERONA AND ECOPARC

The co-digestion plant in Castelleone has been designed and constructed by Biotec Sistemi on the basis of the BTA® Process.

The plant is in operation for 310 days per year, 12 hours per day for the reception and pre-treatment of the co-substrates and 365 day per year, 24 hours per day for the biological step.

The plant has been designed for the treatment of approx. 100.000 ton per year of substrates with the following origins:

- Source separated organic waste (SSOW) 20.000 t/year
- Commercial residues 6.000 t/year
- Agricultural substrates 6.000 t/year
- mainly corn and triticale silage 6.000 t/year
- Cattle and pig slurry 68.000 t/year

The commercial residues do include residues like:

- Glycerin
- Residues from the dairy and baking industry
- Packed residues from the food industry

- Residues from the processing of edible oils and fats

In the figure below, Castelleone plant feeding trend is reported. the

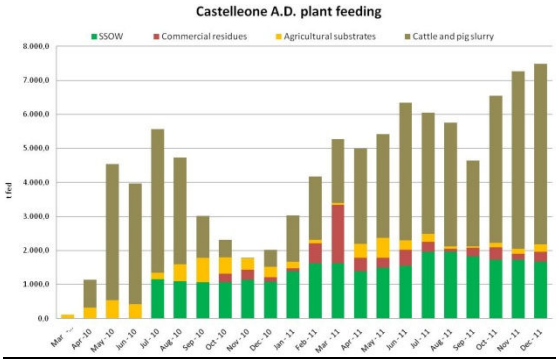

Figure 4: *Castelleone plant feeding trends*

4.1 Flexibility in the reception of the residues

A co-digestion plant should have a high flexibility for the reception of different types of waste. In Castelleone, the following alternatives exists:

- The cattle and pig slurry, coming from five farms, which are located close to the plant and which are connected to it with a network of pipes, are pumped from the farms to an intermediate pumping station, from where they are sent, with a single line, to a storage tank inside the plant. From this slurry tank with a volume of approx. 200 m³ the slurry is pumped into the primary digesters;
- Silages are stored, once a year, in two storage cement trenches with the capacity of 6.000 t. The silage is taken from the trenches through a wheel loader and charged to a feeder with a capacity of 32 m^3 and two independent screw conveyor systems which feeds the silage independently into the two primary digesters.
- The liquid commercial residues and the glycerin are pumped from the tank lorries into two insulated and heated storage tanks with a volume of 40 m^3each, from where they are pumped to the primary digesters.
- The SSOW and the solid commercial residues are discharged at a flat bunker in the waste reception building (max storage volume 180 m^3). With a front loader the waste is fed on hopper with a belt conveyor system which transports these residues to the pre-treatment step.

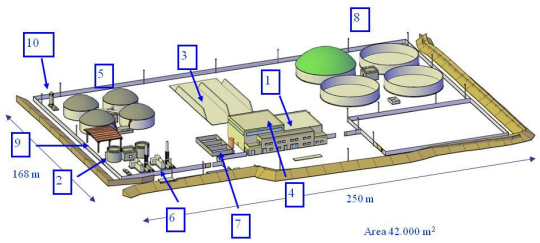

Figure 5. *Castelleone plant layout: (1) reception; (2) manure storage; (3) agricultural substrates storage, (4) pretreatment and sanitation; (5) anaerobic digestion; (6) cogeneration (7) biofilter; (8) digestate storage; (9) rejects storage; (10) biogas flare*

4.2 BTA® Hydromechanical Pre-treatment

The pre-treatment installed in Castelleone is based on the BTA® Hydromechanical Pre-treatment, which consists of two main steps:

- In the first step, in the BTA® Waste Pulper, the digestible organics are defibred and dissolved and the obtained organic suspension is pumped through an internal sieve with 10 mm mesh size, thus retaining all impurities bigger than 10 mm. These are removed in posterior phases of the pulper cycle either as heavy fraction (metals, stones, glass, bones) or as light fraction (plastic, textiles, woody material).
- In the second step, the impurities smaller 10 mm, which are still contained in the organic suspension, the so called grit fraction (sand, small stones, glass splitters, egg shells), are removed in the BTA® Grit Removal System.

The cleaned organic suspension is then pumped to the sanitation step.

Figure 6: *Castelleone pretreatment area*

4.3 Sanitation step

In order to allow the use and spreading of the digestate on the farmland, the suspension is subjected (according to current law) to a sanitation phase, necessary to ensure the elimination of pathogens.

Sanitation of the suspension is made heating it at 70°C and maintaining the suspension at that temperature for one hour. The third requirement, a particle size smaller than 12 mm, is guaranteed by the mesh size (10 mm) of the internal sieve in the BTA® Waste Pulper.

This step is executed in a batch operation in three tanks. The cleaned suspension is heated up to 70°C and is pumped into one of the three insulated sanitation tanks, kept at this temperature in the second while at the same time the third tanks is being emptied.

The suspension is heated in tube heat exchanger using:

- The heat recovered from the suspension in the output of the sanitation, which is then cooled down to a temperature close to 38°C (necessary for the mesophilic digestion process);
- The available heat from the cooling system of the co-generators.

After the sanitation, the suspension is pumped to the primary digesters, where it is mixed with the other streams: liquid residues which do not need a pre-treatment (other then sanitation which can be done in the liquid storage tanks) and manure , which are pumped to the digesters; silages which are loaded to the digesters.

4.3 Anaerobic digestion

The plant in Castelleone has four insulated concrete digesters (two primary and two secondary digesters) with a capacity of 1.800 m^3 each. They are mixed with lateral Biotec stirrers, which ensure a constant and perfect mixing of the suspension.

The anaerobic digestion is carried out in the mesophilic range.

The biogas is stored in a gas meter (elastic membranes) above each digester. The maximum storage volume per digester is 500 m^3.

Through the controlled release of air inside the digesters, the hydrogen sulfide (H_2S) is converted by microorganisms in elemental sulfur, which enters in solution in the suspension.

4.4 Gas valorization

The biogas produced is send to two CHP units with a total electrical power of 1,67 MW_{el}.

The buffering volumes of silages, suspension, liquid waste and glycerin allow to remote control such streams to the digesters with the goal to operate the CHPs close to maximum load.

4.5 Use of the digestate

The digestate is partially pumped to a thickening unit to separate the filtrate, which is recycled to the wet pre-treatment section as process water, from the thickened suspension, which is sent to four storage tanks. Also the digestate is pumped to the storage tanks. The first tank is covered and connected to the biogas collection system, to collect the residual biogas and to reduce the spread of odors.

The digestate is pumped from the storage tanks to the five nearby farms using the same network of pipes of the manure, where it is used as fertilizer. The farms use also their pre-existing manure storage tanks to reach the required storage capacity of 6 months.

4.6 Plant results

In 2011 70.000 tons of digestate were produced and re-used as fertilizer in farmer's fields.

Pretreatment rejects were on average 11 % (8,8% light fraction, 2,4% heavy and grit fraction) of the material fed to the pre-treatment (SSOW + Commercial Residues). In autumn 2011 Biotec has introduced a new dewatering system of the light fraction which has increased the light fraction TS, therefore the amount of rejects in 2012 is expected to be lower.

In 2011 12.969 MWhel, corresponding to an average energy power generation of 1,48 MWel, were produced. During the firsts months of 2012, the average power generation was 1,59 MWel. In 2011 the two cogeneration units worked for 16.210 hours, corresponding to 93% of the available yearly hours, while in the firsts months of 2012, the cogeneration engines worked for the 98% of the available yearly hours, producing 95% of the maximal electrical power energy that the engines can generate operating 24 h/d at full load.

Plant electrical energy consumption was 23.5% of the overall the plant energy production in 2011, during 2012 this percentage decreased to 21.8%.

5 CONCLUSIONS

Especially in Europe, A.D. of OFMSW has established to be energetically, environmentally and socially the most suitable treatment for OFMSW, combining the reduction of MSW to be landfilled in terms of quantity and pollutant charge, with the production of renewable energy and the recovery of high value material. However, different A.D plant have failed not attending the design capacity mainly due to a low impurities removal efficiency. BTA® process achieve an intensive and highly flexible pretreatment thank to BTA® Hydromechanical Pre-treatment. Ecoparc 1 plant suffered low performance (low biogas production and plant capacity and high reject material production). After Biotec-BTA® refurbishment, the plant achieved an average specific biogas production of 154 Nm^3/t in 2011 and the rejected material decreased to 20,3% of the total MSW fed, leading to a higher overall plant availability and economical profitability.The co-digestion of biowaste and commercial residues with agricultural residues is a good example of integration between private and public interests, leading to different environmental, economical and social advantages for environment, farmers and waste treatment companies. The anaerobic co-digestion plant of Castelleone treats biowaste, commercial residues, agricultural substrates and cattle and pig manure. In 2011 and 2012 an average energy power generation of respectively 1,48 MWel and 1,59 MWel were produced by the cogeneration units, which worked for 93% of the time in 2011 and 98% in the firsts five months of 2012. A specific energy production of 422 kWh and 185,4 Nm^3 of biogas per ton of SSOW and commercial residues fed was estimated. Castelleone plant is a successful example of anaerobic co-digestion plant, combining environmental, public and private interests.

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