IMPLEMENTING ANAEROBIC DIGESTION FOR MUNICIPAL SOLID WASTE TREATMENT: CHALLENGES AND PROSPECTS

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ABSTRACT

Modern environmental needs, as well as European and national legal framework, force for the construction of a primal infrastructure and the implementation of projects that will assure protection of the environment and of human health. Municipal solid waste management is linked directly with the reduction of biodegradable fraction and total waste mass disposed to landfill sites. Research and development in solid waste treatment technologies has provided us with very important and flexible solutions.

This paper analyses the implementation of a waste management project through an integrated mechanical-biological treatment scheme. Particularly, it analyses the key characteristic of an anaerobic digestion plant for processing municipal solid waste. The basic engineering parameters, local conditions and legal requirements are reviewed.

Furthermore, due to the current financial environment, this paper emphasizes the need for conducting a thorough technical-economical analysis and evaluation of product marketability. More specific, it examines capital and operational cost centres, life cycle cost issues and potential end-product outlets.

Keywords: municipal solid waste, mechanical biological treatment, waste treatment products, dry anaerobic digestion, composting

1. Introduction

The proper management of the biological fraction of municipal solid waste (MSW) has become prominent issue for the European Countries. Even today in many Countries landfill remains the most common final destination for waste bringing about a considerable amount of environmental damages. European legislation, mainly through the 1999/31/EC directive - known as the “landfill directive” - is moving toward safer landfills, both setting targets for the reduction of biodegradable waste disposal and requiring stringent technical rules for landfill construction, engineering, management and aftercare. Amongst many other provisions, an explicit prohibition of untreated waste disposal is provided by the directive in order to prevent or reduce negative effects on the environment and human health.

In addition, the Waste Framework Directive (2008/98/EC) defines specific targets for preparation for reusing and recycling; namely, by 2020, the preparing for re-use and the recycling of waste materials from households and possibly from other origins shall be increased to a minimum of 50% by weight, at least involving paper, metal, plastic and glass. Separate collection of the organic fraction is recognised to be the keystone to achieve further diversion rates, and a specific article encourages separate collection and recovery of this kind of waste.

Given this framework it has become urgent to provide safe, efficient and flexible industrial solutions to support the transition from unselected MSW management towards the separate collection of organic waste by making it possible a gradual reduction of biodegradable waste to landfill. The teaching and the experiences of past decades show that the path toward the integrated waste management is made up of a number of small steps and actions that combined together contribute to the realization of a real industrial branch. The following figure represents the steps that are usually enforced in order to improve a country's waste management system.

Figure 1: Steps and actions for integrated municipal solid waste management.

In this view, the real need is to provide flexible MBT plants that may follow the path towards the complete implementation of the EU regulation. This requirement stimulates treatment options and technologies, among which aerobic and anaerobic mechanical biological treatments (MBT). Today, even if still to a lesser extent than well established composting and aerobic stabilisation systems, the anaerobic approach to municipal waste stabilisation and/or recovery represents a spread and proven solution, when approaching integrated waste management strategies.

2. Technological overview

Biogas is a mixture of methane (CH_4) and carbon dioxide (CO_2). The only biological treatment process that can produce biogas is anaerobic digestion. Anaerobic digestion differs from aerobic composting in that the degradation of biodegradable materials occurs in absence of oxygen. The process also produces a digestate.

Over the years, studies and applications of anaerobic digestion have brought to a differentiation of technologies. The main distinction is based on the dry matter of the substrate fed to the digester. Anaerobic digestion technologies can be divided in the following groups (Boyer, Confalonieri and Favoino, 2013):

- Wet digestion, where the substrate shall have a dry matter content lower than 10%
- Dry digestion, where the substrate shall have a dry matter content higher than 20%
- Processes which are run at intermediate dry matter contents are less common, and are generally referred to as semi-dry.

The first one has its roots in the first applications of anaerobic digestion to sewage sludge in waste water treatment plants; liquid waste and organic waste characterised by a high moisture content and a relatively low contamination by contraries are the main substrates. Dry anaerobic digestion was specifically developed for approaching the treatment on unsorted waste (MSW), or organic waste rich in dry or hardly dilutable fractions such as wood, plastics, etc, in order to avoid hard pre-treatments, maintenance and consequent costs.

A second classification is based on the temperature at which the anaerobic process is performed. The following classes of process are then identified (Boyer, Confalonieri and Favoino, 2013):

- Psychrophilic processes (average temperature 20°C)
- Mesophilic processes (average temperature 38°C)

- Thermophilic processes (average temperature 55°C)
- Extremely thermophilic processes (temperatures between 65-70°C).

Mesophilic and thermophilic processes are the most diffused ones at industrial scale; the first ones are generally characterised by lower capital and management costs, and by “robust” biological processes. Thermophilic reactors, on the other hand, can achieve higher specific biogas productions, although maintaining a proper process balance can be harder and more expensive.

Reactors loading systems define either batch processes, or continuous processes; in the latter case, the digesters are periodically (daily or every few hours) fed with a given amount of waste, and an equal amount of digestate is withdrawn. If batch technologies are considered easier to be managed, a higher specific biogas production is generally granted by continuous processes, where microbial kinetics are constantly kept at their best.

Figure 2: An example of a continuous wet reactor (on the left) and a batch dry battery of reactors (on the right).

3. Implementation of anaerobic digestion

Compared to other organic biomasses suitable for anaerobic digestion, municipal waste holds the peculiarity of being a heterogeneous material both in its organic matter composition, its physical state and in the presence of contraries. The choice of the best suitable anaerobic option is crucial for the successful project implementation. Batch dry anaerobic digesters are often indicated for the construction of robust installations with low maintenance requirements. Dry processes produce less wastewater than the wet systems and require less equipment for managing waste streams. Furthermore, problems, such as settling, foaming and flotation that occur in wet digestion reactors during MSW treatment, are avoided (Archer, Baddeley, Klein and Schwager, 2005).

The implementation of batch dry anaerobic digestion technology for the treatment of MSW is under development, in Ilia Prefecture, west-central Greece. The project is designed to accept a nominal total 80,000 tonnes per annum (tpa) of municipal solid waste.

3.1. Basic project description

The overall technical solution refers to a waste management plant, containing several areas and facilities, each contributing differently to the Project objectives of recovery and recycling, residual treatment and energy recovery:

- Mechanical Treatment Facility (MTF), where the dry fraction (paper/cardboard, plastic, metal) is separated from the organic fraction. The dry fraction is then separated via various methods in order to recover recyclable materials.
- Biological Treatment Facility (BTF), where the organic fraction of waste is subjected to anaerobic digestion (AD) and biogas is produced to be utilised for energy generation.

The digested matter resulting from the anaerobic digestion is further treated in an aerobic composting plant for the production of compost.

- Mechanical Composting Facility (Refinery Unit), where compost is refined and contaminants - such as plastics, aggregates and glass - are removed.
- Residue Acceptance Area, located within the designated landfill site, adjacent to the MBT site, for the disposal of treated residues.

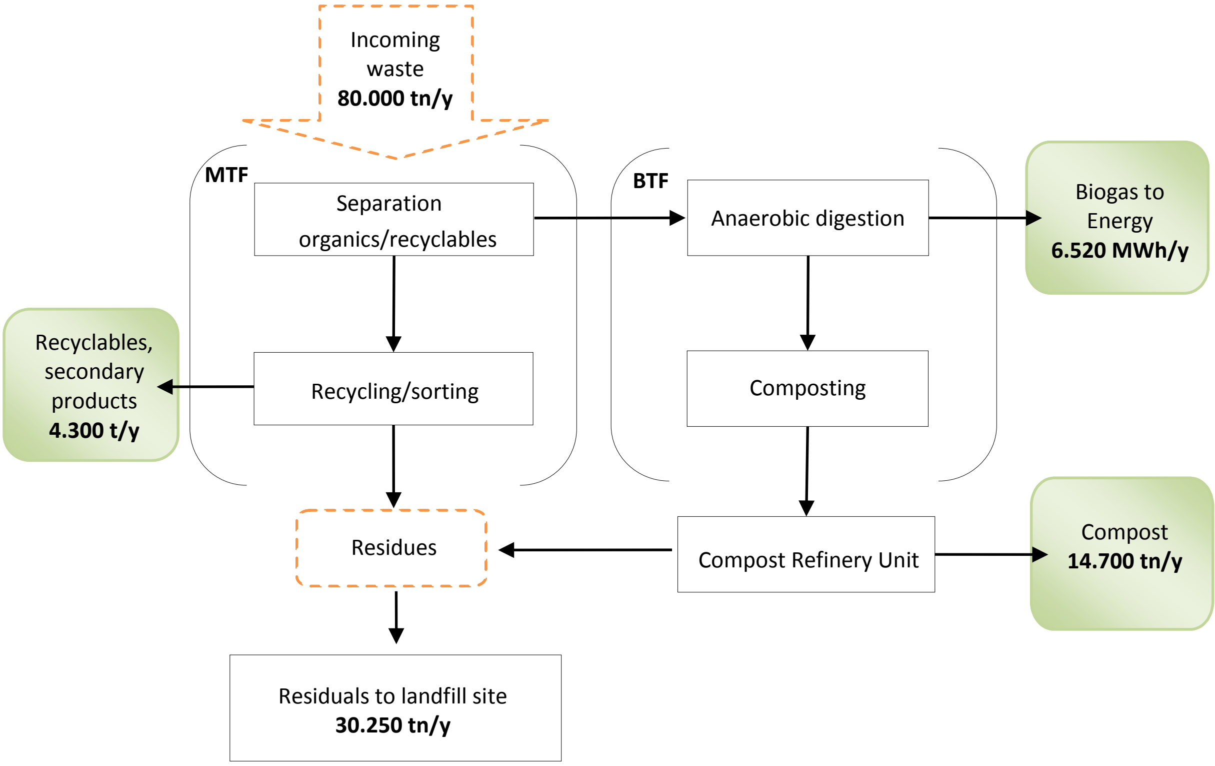

Figure 3: The waste infrastructure network mass flows

Waste is delivered to a concrete deep bunker, which is contained within an enclosed building of the Mechanical Treatment Facility. Waste is fed forward from the reception bunker to the MTF using a crane and grab arrangement. The MTF is a single production line which consists of a manual handling presorting stage; a bag opener; a 80mm rotating sieve; overband magnets; a flip-flop vibrating sieve; a ballistic separator; optical separators; an eddy current separator; and a handpicking stage.

The Biological Treatment Facility receives the organic fraction that is recovered by the rotating sieve, the ballistic separator and the flip-flop vibrating sieve. The BTF section consists of 12 anaerobic digestion (AD) cells, 6 aerobic composting cells; 2 Combined Heat & Power (CHP) engines; 2 leachate storage tanks; 2 gas storage chambers; 1 effluent gas treatment system; and the necessary auxiliary systems. The BTF is focussed around a dry batch AD modular system, where the biological process is undertaken in 12 cells. The material is held in each cell for 21 days. Each cell is provided with a door, which when closed provides an air tight seal, biogas management system, ventilation, and wetting systems. Biogas from the gas chambers is fed through condenser stations (to remove condensate from the gas) prior to burning within one of two CHP engines, which results in electricity and heat being produced. The electricity is exported and the heat is used in the heat management system to maintain the temperature in the AD cells. Following the AD process, the organic material is then transferred to one of 6 composting cells. The retention time in each cell is 14 days and is under constant aeration.

When the composting process is completed, the composted material is transported to the Refinery Unit. Processing of the organics is through a rotating sieve and a densimetric table. This allows large particles to be separated from the organic rich fines or Compost Like Output

(CLO). The large particles are discharged to skips for disposal and the CLO is driven to the maturation area.

3.2. Key factors and design parameters

The total plant has a nominal capacity of 80.000 tpa (or 36,6 tn/hr), while the Biological Treatment Facility is designed to accept 36.000 tpa. The choice of the best suitable anaerobic option for the given substrate was accompanied by proper evaluations on waste mechanical pre-treatment. The main purpose of pre-treatment is to increase biodegradability thereby, enhances the digestion process. The size reduction of the particles and the resulting enlargement of the availability specific surface can support the biological process by harmonizing the digestion time in case of heterogeneous input (Palmowski and Muller, 2000).

According to the Reference Document of Best Available Techniques for the Waste Treatment Industries (European Commission, 2006), the anaerobic digestion process leads to a production of methane, with a theoretical methane production of 348 Nm^3/tn of COD. Anaerobic digestion generally produces 100-200 Nm^3 of COD per tonne of biological municipal waste. Biogas generation is very sensitive to feedstock, one plant found volumes ranging from 80 to 120 Nm^3 per tonne depending on the waste input. In Ilia prefecture project, biogas is use for the production of electric and thermal energy, which is estimated to be 6.520 MWh/y and 5.900 MWh/y, respectively.

A principle issue associated with the stability of the AD process is bacterial nutritional requirements. In Ilia prefecture project, the stability of the bacterial population is enhanced by the recirculation of 20-25% digestate material into each new digestion cycle. Furthermore, leachate recirculation, pressure and temperature have been set as key parameters for the process control system. A mesophilic process has been implemented, with temperature being adjusted at 38 - 40^{o}C. The heating distribution system embedded under floor, contributes to temperature control. The irrigation of the material in the digester with leachate depends on the initial moisture content of the material (seasonal variation). The amount of irrigation is adjusted by the operator depending on the material.

4. Economics of anaerobic digestion

The costs for AD are likely to vary in accordance with the following factors:

- Costs for acquisition of land;
- The choice of process (there are many variants);
- The input materials used (which, amongst other things, affect biogas generation);
- Efficiency of energy recovery (and whether recovery is of electricity, heat, or both);
- Price support for energy production (and effect on revenues);
- Regulations concerning the conditions for utilisation of digestate; and
- Revenues for digestate (composted or otherwise).

Data for the capital cost of anaerobic digestion indicates that there is a wide variation in costs. The range arises due to the degree of front-end pre-treatment required, the type of anaerobic digestion process and the requirements for receiving and treating the wastes.

According to Greater London Authority (2008) a reasonable cost for a 20.000 tpa AD plant taking food wastes i.e. involving minimal pre-processing and including civil, mechanical, electrical, engineering, buildings, weighbridge, and design and commissioning costs but excluding land purchase, is around 4,2-5,6M €. Respectively, the operating costs may be of 550-700k € per annum, i.e. 27–36 € per annual tone of capacity. This cost includes labor, maintenance, consumables, management, utilities, but excludes finance and profit margin. Gate fees charged by privately owned commercial operations, which includes finance costs and profit margins etc., are around 55-70 €/tn.

In Ilia prefecture project, the construction cost for the whole MBT plan, including intensive mechanical facility treatment, biological treatment facility, refining unit and supporting works, is estimated to be 29-31M €. The operational cost, for covering personnel, maintenance, consumables, management and utilities requirements, is estimated around 38-39 €/tn.

5. Results and conclusions

Mechanical Biological System can be considered a stage of a virtuous path toward the realisation of a proper integrated municipal solid waste management system. The important role of anaerobic digestion in the frame of the integrated waste management is linked with a number of factors, such as biodegradable waste diversion for landfill, separate collection targets, market widening for products and economic grants.

Flexible design and long term perspective make it possible to imagine a technological improvement, in order to achieve the best performance in biodegradable municipal waste treatment, material recovery and biogas production. In this view the anaerobic digestion technology is at a stage of maturity that will make it possible to be adapted to different needs and can be merged and combined in order to provide an efficient and cost effective solution towards a sustainable waste management.

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