Anaerobic Digestion of the Organic Fraction of Municipal Solid Waste in Europe
– Status, Experience and Prospects –

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Abstract

Anaerobic digestion has come of age in the field of the treatment of the organic fraction derived from municipal solid waste, more so than any other alternative treatment technology developed in the last 20 years. With a total of 244 plants and a capacity of almost 8 million ton of organics treatment capacity, anaerobic digestion is already taking care of about 25 % of the biological treatment in Europe. In The Netherlands and Belgium, it is expected that 80 % of the composting plants will have anaerobic digestion as the primary treatment technology by the year 2015. Long term successful experience has made anaerobic digestion the preferred treatment technology for the MSW organics, making use of a variety of technological approaches and systems. It can only be expected that anaerobic digestion will continue to increase on a steady basis, not only because of the production of renewable energy but also because of the reduction in odor potential and surface area required.

1. Introduction

The management of municipal solid waste (MSW) has been subject to major developments during the past 20 years. At the end of the '80s, landfilling and mass burn incineration were still the major methods by which MSW was disposed of. Composting made up a small percentage of the disposal and was on the decline because of major quality challenges due to heavy metals and inert materials in the final end-product. Recycling was limited to paper and glass and easily recoverable materials.

Major progress was made in all areas of waste management but the introduction of anaerobic digestion into the treatment of MSW is one of the most successful and innovative technology developments observed during the last two decades in the waste management field. Anaerobic digestion has become fully accepted as a proven and an even preferred method for the intensive biodegradation phase of organic fractions derived from MSW.

Even though continued progress has been made with other alternative treatment technologies (gasification, pyrolysis, plasma, biological drying, etc.), these technologies have by far not seen the same widespread implementation that anaerobic digestion has been able to achieve. In Europe alone, 244 installations dealing with the organic fraction of MSW as a significant portion of the feedstock have been constructed or are permitted and contracted to be constructed (up to 2014). The cumulative capacity of all of these anaerobic digestion plants amounts to 7,750,000 ton per year of organics going into the digestion phase. If one assumes 300 kg of biodegradable waste generated per person and per year[1], this capacity represents about 5 % of the biodegradable waste generated across Europe (excluding former USSR-states) by 550 million inhabitants. In addition, this capacity represents 25 % of all biological treatment, which is estimated at around 20 % of all municipal solid waste disposal in Europe. However, it should be noted that probably 10 to 15 % of the plants are no longer in operation. This could be partially compensated by the too low (inventoried) capacity to be constructed in 2014, as there are undoubtedly projects that are not included in the assessment yet.

Countries having the largest capacity installed are Germany with about 2 million tons of annual capacity, and Spain with 1.6 million tons (see Figure 1). However, if one adjusts for the number of inhabitants, then countries like The Netherlands and Switzerland become the highest[2] in installed annual capacity of respectively 52,400 tons per million people and 49,000 tons per million people (see Figure 2). The Netherlands have implemented a strategic initiative in order to promote anaerobic digestion of MSW-derived organics during the last three years. The country has a very well developed infrastructure for natural gas but as the gas wells are running dry in the North Sea, the government is intent on producing a large amount of biomethane which can be distributed across the country. The Netherlands have the ambition to replace 15 to 20 % of the natural gas by *green gas* by 2030.

One big difference between the two countries is that the sizes of the plants are very different. The average size of an anaerobic digester is 31,700 tons per year in Europe but there exists a big variation. The Netherlands has large plants (average capacity = 54,000 tons), while Switzerland installed many small plants (average capacity = 14,000 tons). This reflects the dense population in The Netherlands and the drive to lower costs, while in Switzerland the split is due to geographical complications in transporting waste from one area to another.

[1] Municipal Solid Waste (MSW) generation in the EU-27 has been stabilizing at around 520 kg/capita since 2000. It is assumed that about 60 % of that waste is organic.

[2] Except for Malta and Luxemburg, but these countries can be considered as an exception due to their small surface.

The largest plants can be found in France (average size of 56,130 tons per year) and the smallest plants can be found in Sweden (average size of 10,000 tons per year).

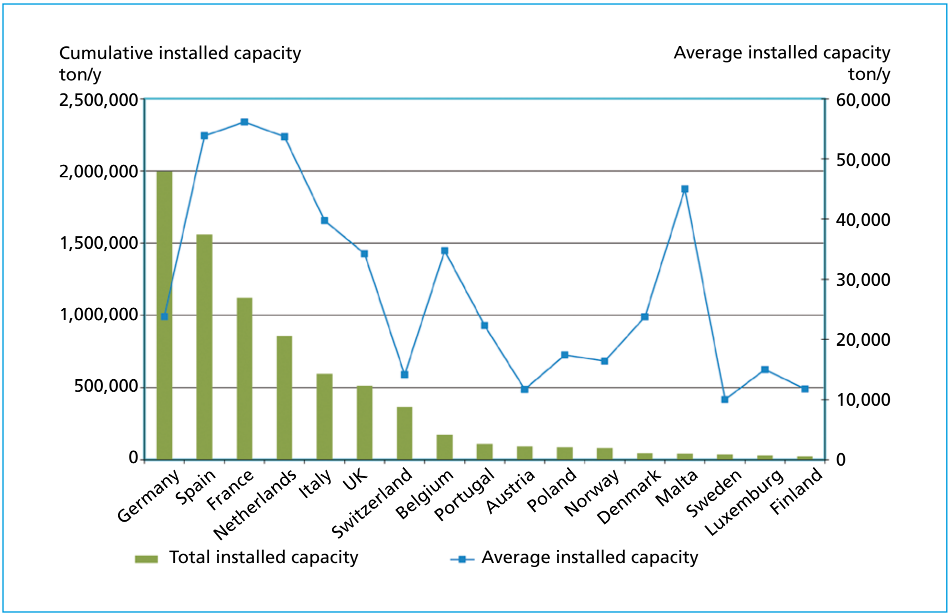

Figure 1: Total installed capacity per country

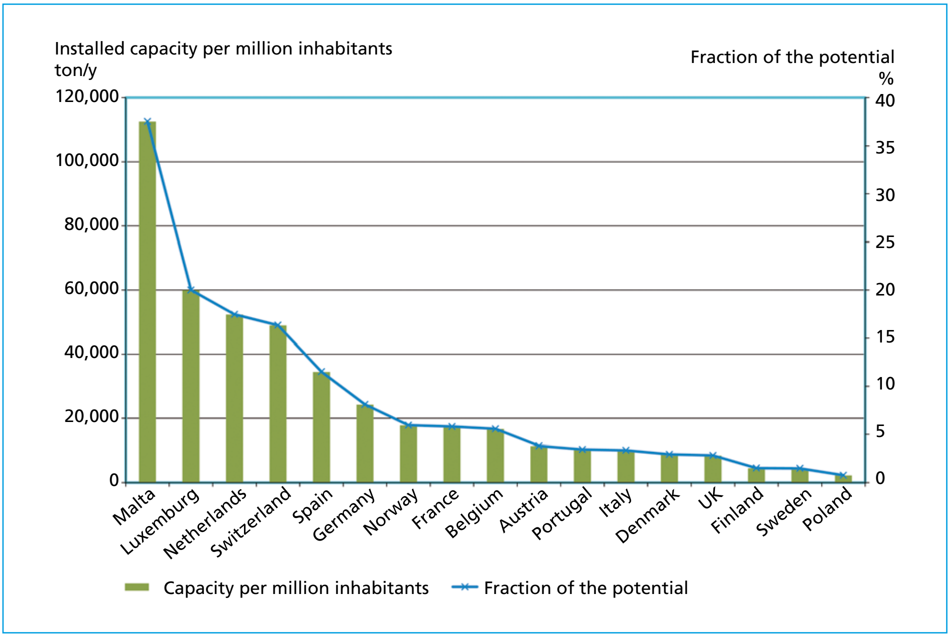

Figure 2: Installed capacity per million inhabitants and per country

The above mentioned figures show that geographical parameters and country policies have a strong impact on the type of AD plants that a country will implement. France does not stimulate source separation and likes to concentrate everything in cities or metropolises (resulting in large treatment facilities), while Sweden focuses on local (small scale) digestion of biowaste. From an economic perspective, plants should be at least 30,000 ton per year in capacity into the digester, and preferably even 40,000 to 50,000 ton per year, unless other restrictions or financial aspects apply.

2. The rise of anaerobic digestion

The first anaerobic digestion plants were all constructed for the treatment of mixed municipal solid waste, as no source separate collection existed at the time. The rapid rise of source separate collection in the '90s triggered the implementation of a large number of anaerobic digestion plants, even though the technology was still in its infancy. It was in the first place the number of composting plants that increased dramatically again after years of decline, and a number of those plants opted for anaerobic digestion. The fact that the feedstock derived from source separate collection was much cleaner, spurred the development and adaptation of more conventional digestion technologies, sometimes with mixed success.

Anaerobic digestion used to be anathema in the world of composting. Anaerobic meant big operational problems and odor issues. Now, anaerobic digestion and composting go hand in hand in many ways. Anaerobic digestion is used to replace the intensive aerobic composting phase but is always followed by a dewatering step to produce a digested cake that can be further aerated and turned into a high quality compost. Or a fraction of the waste (the wetter and most digestible fraction) is separated and digested, while the larger woody waste is treated in simple green waste composting plants or is used as a bulking agent for the treatment of the digestate coming from the wetter fraction.

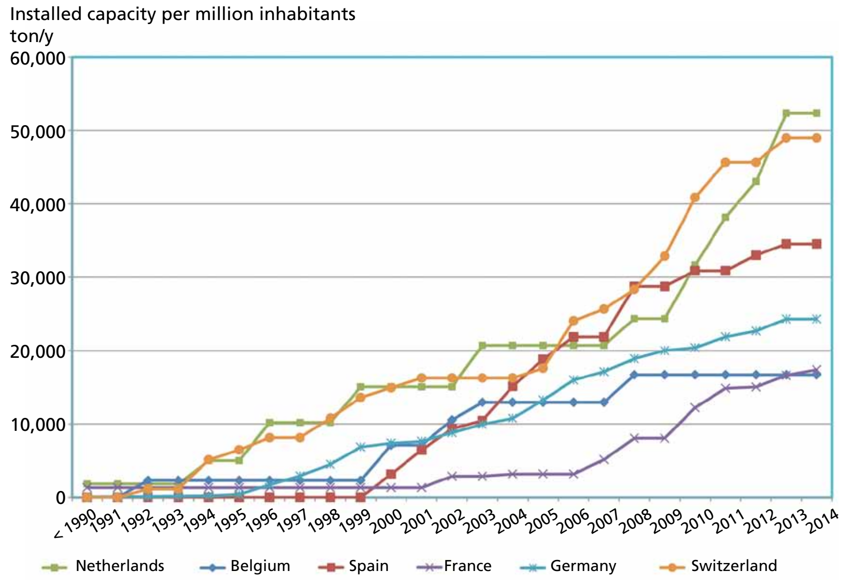

Figure 3: Increase in capacity per million inhabitants per country

The construction of digestion capacity has not been explosive but steady. It cannot be said that anaerobic digestion is cheaper than aerobic composting, even compared to in-vessel composting. However, anaerobic digestion offers the opportunity to produce renewable energy, to reduce the surface area of the site and to significantly reduce the odor nuisance of the plants. All in all, a composting plant with anaerobic digestion offers a higher quality of treatment but at an extra price, except for specific cases.

In Figure 3 an overview can be found of the increase in capacity in the most important countries (countries with the highest installed capacity per million inhabitants). Countries like Switzerland, the Netherlands and Germany were early adopters (and whereby the Netherlands seems to be only now on cruising speed), while France and Spain started much later with the implementation of anaerobic digestion as a treatment method for MSW. The leveling off in 2014 is due to the limited number of plants that are now already known to be contracted for startup in that year.

3. Current state-of-the art in Europe

3.1. Method description

In order to get an accurate overview over the status of anaerobic digestion of the organic fraction of MSW in Europe, the following criteria were taken into account in order to be taken up in the assessment:

- At least 10 % organic solid waste from household origin needs to be treated in the plant, with a minimum capacity of 3,000 ton per year.
- The capacity taken into consideration is the designed capacity for the plant, unless specified differently by the supplier/operator. For biowaste, the total capacity of the biowaste plant was used while for mixed and residual waste plants, the actual capacity going into the digesters was used.
- Plants were not eliminated if operation ceased.
- The plants taken into consideration have to be at least under construction or contracted and situated in Europe. A prognosis was made for 2013 and 2014 based on awarded tenders.

With these criteria, a quantitative analysis was made on the installed annual capacity as such. But as the anaerobic digestion plants can be divided into different *subcategories*, a more thorough analysis was made on the installed capacity. The most important process parameters that can be used to distinguish between the different anaerobic digestion plants are operating temperature, moisture content, complexity, feedstock and codigestion. Below, some trends per process parameter are presented.

3.2. Mesophilic or Thermophilic

Mesophilic digesters operate at a temperature between 35 °C and 40 °C, while thermophilic digesters operate between 50 °C and 55 °C.

Cumulative installed percentage in 2014		
Parameter	Temperature	
	Mesophilic	Thermophilic
Cumulative installed %	67 %	33 %

Table 1: Cumulative percentage of mesophilic and thermophilic capacity installed in 2014

Mesophilic digestion has always been predominant, mainly because it is the temperature of choice for most of the applications in the field of wastewater, manure and sewage sludge digestion. Other reasons are the smaller need for heating and because it was considered a more stable process. However, thermophilic digestion has always played an important role in the digestion of the organic fraction of MSW. Except for the period of 2005-2007 when a lot of wet mesophilic plants were installed, thermophilic digestion has always had a market share of about 30 to 40 %. For the period 2010-2014, this will even be slightly higher. The need for heating plays a smaller role in dry digestion systems, while biogas production rates can be 30 to 50 % higher compared to mesophilic digestion, using the same technology. Stable thermophilic large scale performance has been proven over many years of operation by several technologies.

3.3. Single feedstock or Codigestion

Table 2: Cumulative percentage of solid waste and codigestion capacity installed in 2014

Cumulative installed percentage in 2014		
Parameter	Codigestion	
	Solid waste	Codigestion
Cumulative installed %	89 %	11 %

In household waste digestion, the addition of other products to the organic fraction of MSW (=codigestion) used to be rather the exception in the last 15 years. This can be explained by the fact that AD plants treating MSW are usually *dedicated* plants (e.g. with a pre-treatment tailor made to a specific waste stream with a particular composition). However, a small augmentation in the number of codigestion plants can be observed (up to 13 % of the installed capacity in the last 2 years). Probably, the strong rise in codigestion facilities in the agro-industrial sector has shown that adding *co-products* could also be an option for operators of MSW-plants to improve their process or the economics of the plant.

Nonetheless, it is important to realize that some facilities foresee this option but make no (or little) use of it and in general, the amount of co-products is rather low (e.g. 10 to 15 %).

3.4. Single phase or Two Phase

Table 3: Cumulative percentage of one phase and two phase capacity installed in 2014

Cumulative installed percentage in 2014		
Parameter	Complexity	
	One phase	Two phase
Cumulative installed %	93 %	7 %

The number of plants that apply two-phase digestion for the treatment of MSW, in which there is a separate hydrolysis phase followed by the actual methanization phase, has continued to decline since the beginning of the nineties. Many high-rate one-phase systems have been installed and have proven to be efficient (such as the DRANCO system). No immediate change is expected in the trend of this parameter, also due to the higher investment and operating costs for running two different processes.

3.5. Wet or Dry

In general, dry digestion is considered to have > 15 % total solids (TS) in the digester.

Table 4: Cumulative percentage of wet and dry capacity installed in 2014

Cumulative installed percentage in 2014		
Parameter	**Moisture content**	
	Wet	Dry
Cumulative installed %	38 %	62 %

In the beginning of the '90s, most digesters were working at a high total solids-content (about 70 % of the installed capacity was *dry*). Dry digestion has almost always been predominant, excluding the (above mentioned) period of 2005-2007 with the construction of large wet digestion systems in Spain.

During the last 5 years, dry digestion accounts for about 70 % of the installed capacity (resulting in a cumulative market share of about 62 %).

3.6. Biowaste or Mixed Waste

Table 5: Cumulative percentage of wet and dry capacity installed in 2014

Cumulative installed percentage in 2014		
Parameter	**Feedstock**	
	Biowaste	Mixed waste
Cumulative installed %	55 %	45 %

The parameter *feedstock* probably shows the highest variation during the evaluated period (1990-2014). In the beginning, the few digesters that were installed were all treating mixed waste (because there was hardly any source separation). When more and more countries started to implement source segregation in the nineties, the number of AD plants treating biowaste increased rapidly. During the period 2000-2006, many plants were installed in countries were source separation is not common (resulting in a sharp rise in the amount of mixed waste plants). However, during the last period (2006-2014), an upward trend of plants treating biowaste can be observed, as source separate collection is implemented in more and more countries. By 2014 about 55 % of the installed capacity is destined to treat biowaste.

4. Experience

Many anaerobic digestion plants have operated reliably for 10-15 years and to even more than 20 years. Based on the experiences gained, one can only expect that plants will become more and more reliable, as mistakes are corrected and less performing technologies are eliminated.

The problems must not be underestimated in building and designing new plants though, not only from a technical perspective but also from a biological perspective. A thorough knowledge of the composition of the waste is useful in order to accurately assess the most appropriate technology as well as the economic ramifications. Different feedstocks in different countries will have widely varying properties and biogas yields.

Experience has shown that not all plants and technologies have been equally successful. Mixed or residual waste (residual waste is the waste left after source separate collection of the biowaste fraction) digestion is the most challenging as the feedstock poses the most problems due to the high level of contaminants in the organics. Sedimentation and formation of a floating layer need to be prevented by either operating under dry conditions or eliminating the contaminants in an effective pretreatment in order to allow wet fermentation. Also the treatment of source separated organics needs to be carefully designed. Some source separated organics contain large amounts of sand due to the sandy soils in the area and depending on the amount of yard waste that is added to the feedstock, while the woody waste can form a floating layer.

Alternative solutions have been to limit the kind of waste that is collected for digestion to pure food waste (excluding wood or yard waste) or to mix in large amounts of yard waste and treat the wastes in simple tunnel dry batch systems.

5. Prospects

The prospects for anaerobic digestion are steadily improving, and a continued steady increase of capacity can be expected. Anaerobic digestion will continue to replace the first intensive composting step for the treatment of more and more biodegradable waste from MSW. Countries like The Netherlands and Belgium will have 80 % or more of the existing composting plants equipped with an anaerobic digestion system by the year 2015, based on the planning. Now already, the vast majority of tenders in the *Supplement to the Official Journal of the European Union* (dedicated to European public procurement) requires anaerobic digestion as the first step of the biological treatment process.

One of the major developments that will undoubtedly continue to increase has been to insert an anaerobic digester into already existing composting plants. Many composting plants that were constructed for source separated organics were aerobic systems as the anaerobic technologies were still in full development. However, these plants are now 15 to 20 years old and need an upgrade. The insertion of anaerobic digestion as a first phase of the treatment process is a topic at almost all of these aging plants. Insertion of an anaerobic digestion allows to use the existing equipment and also retain the same site due to the low requirement for surface area, thereby reducing the investment needed (see Figure 4) and making anaerobic digestion the most economically attractive upgrade of the facility. The biological treatment plant becomes an energy producer (instead of only an energy consumer), and insertion of anaerobic digestion also reduces odor problems.

Figure 4:

Anaerobic digestion plant in Hengelo (The Netherlands) showing integration of an anaerobic digestion into an existing composting plant

Also mixed waste sorting and composting plants and even incineration plants can benefit from the insertion of an anaerobic digestion system for the most biodegradable part of the waste. Several projects have been constructed or are slated for these applications.

Another development in the last five years has been the construction of batch tunnel dry digestion systems (see Figure 5). These digestion systems offer a low technology solution in comparison with the more technologically advanced continuous systems. Sophisticated pumps and processing equipment are replaced by front-end loaders and manpower. Due to the modular nature of these simple systems, they have an advantage for smaller capacities and for plants where stepwise augmentation of the capacity is desired.

Figure 5:

Batch digestion in Germany

From a geographical perspective, a major development of the digestion technology for the organic fraction of MSW can be expected in the previous Eastern European countries where the EU standards and regulations need to be implemented over the coming years. Higher levels of recycling and reduced disposal of organics into landfills will stimulate the expansion of digestion capacity in those countries.

6. Conclusions

Anaerobic digestion has been demonstrated to be a viable alternative waste treatment method for the handling of the organic fraction of MSW and is a fully accepted proven technology. In many cases, it is the preferred treatment technology for the intensive phase of biological treatment. Several countries will have a large majority of the composting or MBT plants equipped with an anaerobic digestion step.

The digestion of the organic fraction of MSW has matured as a technology. Many innovative improvements and developments have been made during the first twenty years. An ever widening variety of technologies offering different approaches have been developed in order to efficiently treat the organic fraction coming from MSW. Anaerobic digestion will play a steadily increasing role in the field of the biological treatment of MSW organics.

7. References

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