Organic solid waste biological treatment facilities: comparative analysis of process schemes

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Abstract.

The biological treatment of the organic fraction of municipal solid waste represents the most spread strategy to pursue the biological stabilization of this residual stream, under either aerobic or anaerobic conditions. Anaerobic digestion is an attractive technology for the conversion of organic substrates into methane, but the handling of the residual stream, namely the digestate, can prove to be challenging, especially in those countries where any Regulation has been enforced to discipline its proper use. In order to overcome this drawback, while taking the greatest advantage from the organic solid waste biostabilization in the circular economy view, the proper combination of both aerobic and anaerobic processes can be implemented. At full-scale the combined anaerobic/aerobic treatment entails a high technological complexity, so that the careful monitoring of the overall process is fundamental to ensure its proper development.This study aims at assessing the process performances of full-scale plants, differently combining the anaerobic process with an aerobic step. To this end, mass flow analysis was used, so as to comparatively discuss the yields of complex biological treatment facilities.

Keywords: anaerobic digestion, biogas, biostabilization, composting, digestate, mass balances

1. Introduction

The source separation of recyclable fractions from municipal solid waste is a well-established activity to pursue the sustainable waste management, aiming at material recovery while reducing waste landfilling (Jank *et al*., 2015). Such approach, addressing the fulfilment of the hierarchical waste management strategy, is now regarded under a circular view. The depletion of natural resources as well as the need to meet both the energy and material demand of a globally increasing population have indeed promoted the development of a circular approach in waste management, so as to close the loop of material cycles (Ghisellini *et al*., 2016). The organic fraction of municipal solid waste (OFMSW) represents a valuable feedstock for the implementation of a circular approach. As biomass, it could be separated into its building blocks, including carbohydrates, lipids, proteins, that can be converted into valuable added products, chemicals and biofuels (Cherubini, 2010; Schieb *et al*., 2015). However, the establishment of sustainable production chains using OFMSW as input material is still in a research stage and the current management practices rely on conventional biological treatments. Composting and anaerobic digestion are the most common processes for the management of source sorted OFMSW. Although the amount of separately collected and treated OFMSW can greatly differ among European Union (EU) Member States, it was estimated that only 30% of the produced OFMSW was source sorted in 2012. Approximately 80% of the source selected OFMSW was composted in EU and the remaining portion treated by anaerobic digestion (Al Saedi *et al*., 2013). It is well known that composting is an aerobic biodegradation process, resulting in the production of a biostabilised material that can be used as soil amendment (Faverial *et al*., 2016; Wei *et al*., 2017). On the other hand, anaerobic digestion is a biodegradation process occurring in the absence of oxygen, with the generation of a methane rich gas, namely the biogas, and an effluent with potential fertilizer properties, referred to as digestate. The digestate management can prove to be challenging, especially in those countries where its qualitative characterization is not formally identified. This condition limits its use on soil and has been addressing the further aerobic stabilization of the digestate aiming at compost production. The assessment of compost quality, although heterogeneous throughout Europe (Cesaro *et al*., 2015a), is legally established, so that compost is used as soil amendment. Combined anaerobic/aerobic treatments represent a suitable strategy to implement a circular approach in OFMSW management, while ensuring the flexibility of the biological processing. However, due to their technological complexity combined anaerobic/aerobic plants require careful monitoring to optimize biological conversion yields and to reduce the production of residues. To this end mass balances can be successfully applied (Cesaro *et al*., 2015b; Pognani *et al*., 2012). Mass balances reflect the application of the law of mass conservation and they are widely used in engineering and environmental analysis as they can be easily adapted to different systems. Making material balances on the substrate, the biomass and the biogas, Fedailaine *et al*. (2015) established a bio-kinetic model to describe the operation of a digester. Such approach is particularly effective to manage the anaerobic process, so as to optimize the methane conversion of organic waste into biogas. However, in the wider context of a full-scale facility operation, the biological process control is as important as the monitoring of the other sections, contributing to the overall sustainability of the implemented treatment. To this end, pure mass balances can be of greater support and, since they are based on the analysis of the mass flows, allow the comparative evaluation of different systems pursuing the same objectives by an easy-to-apply procedure. Aim of this work was in assessing the process performances of full scale plants, differently combining the anaerobic process with an aerobic step via mass balance analysis.

2. Materials and methods

For the purposes of this study the following plants, treating source sorted OFMSW via combined biological treatments, were considered:

- an integrated anaerobic/anaerobic facility located in South Italy, whose process scheme (Figure 1) is described in details in the study by Cesaro *et al*. (2015b);
- a combined anaerobic/aerobic plant sited in Germany.

For the German facility, data were collected from the plant operators with reference to the main treatment units, which are briefly described in the following paragraph. For each plant, mass balances were performed using the data obtained from either field activities or plant manager interview. Results were used to set a comparative analysis between those facilities. They were also discussed with reference to the mass balances of either composting and anaerobic digestion full-scale facilities that have been largely studied in literature (Banks *et al*., 2010; Zhang *et al*., 2010).

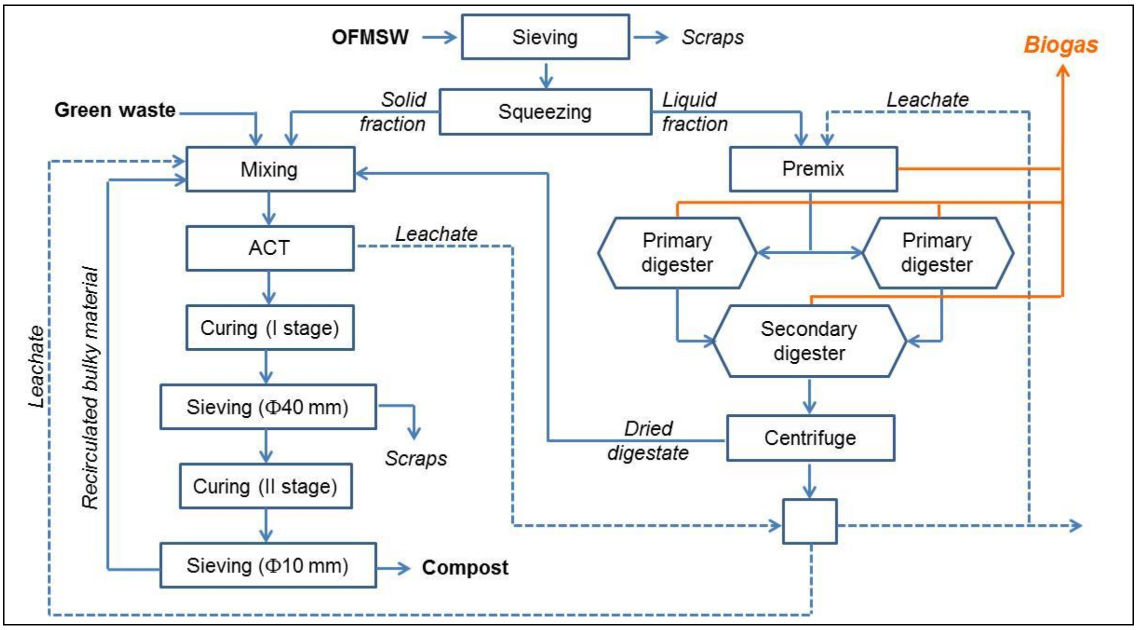

Figure 1. Flow scheme of the Italian combined anaerobic/aerobic plant

2.1 The German integrated anaerobic/aerobic plant

The combined anaerobic/aerobic facility located in Germany treats 40.000 t/year of source sorted OFMSW. The incoming waste is shredded, pretreated to remove impurities and sieved: the oversieve is recirculated to the shredder, while the undersieve is destined to a dry anaerobic digestion process. The digestate is pressed, in order to separate the solid phase sent to composting from the liquid one, which is partly recirculated back to the digester and partly stored in a tank to be directly used in agriculture as fertilizer, in accordance with German regulations. The process scheme of the plant is plotted in Figure 2.

3. Results and discussion

3.1. Mass balance for the Italian facility

In the Italian biological treatment plant, the anaerobic digestion section is integrated with the composting one. The total amount of OFMSW is adequately pretreated to obtain a liquid fraction, destined to anaerobic digestion and a solid one, which is directly biostabilised under aerobic conditions. According to this process scheme, the wet fraction fed to the anaerobic digestion line accounts for approximately 28% (w/w) of the incoming OFMSW. A relevant portion, representing the 42% of the input organic waste constitutes the solid fraction sent to composting, whereas the remaining 30% is removed as scraps during the pretreatment line. The wet fraction is mixed with the leachate originating from the digestate centrifugation, so as to reduce the total solid load to the digesters, and destined to the production of biogas.

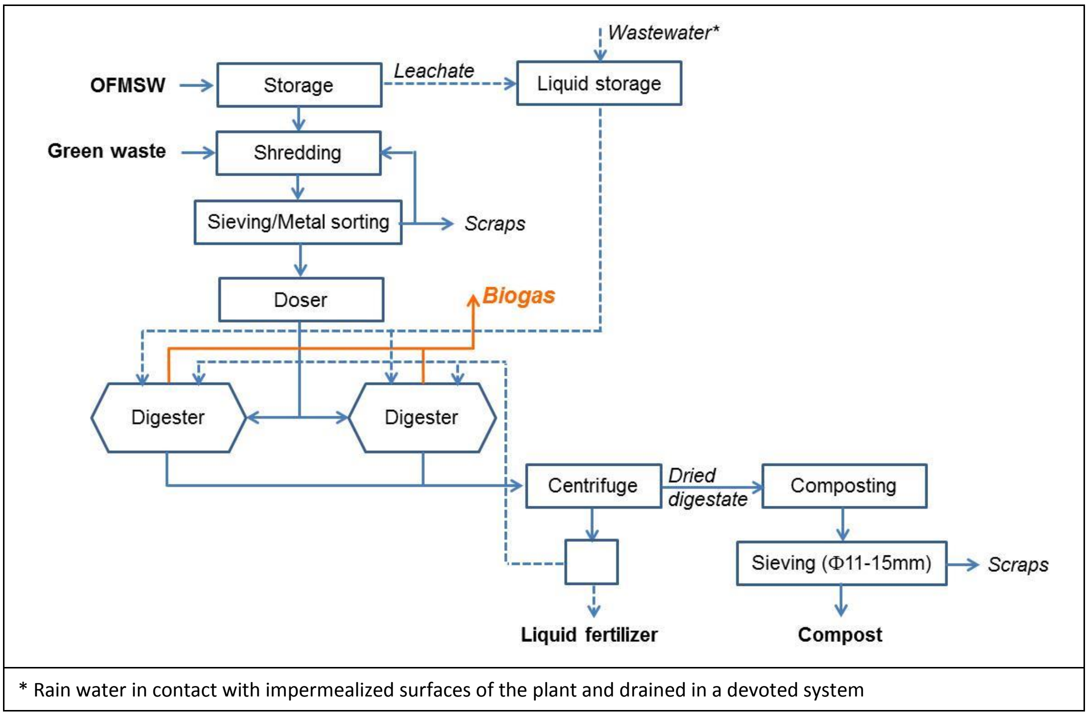

Figure 2. Flow scheme of the German combined anaerobic/aerobic plant

The anaerobic degradation yield of 10% based on the total mass results in the production of 5,043 Nm^3/d. Such value corresponds to 132 Nm^3/t of the input mixture fed to the digesters and it is comparable with the average specific biogas production reported by Banks *et al*. (2011) and equal to 156 Nm^3/t. The slight difference could be ascribed to the operating conditions of the applied anaerobic processes. The quality of the substrate is also a key factor in the definition of the biogas yields. In this case, the slightly lower biogas production estimated for the plant under investigation could be related to the extensive pretreatment via sieving and squeezing that can be responsible of a minor loss of organic material.The aerobic section is fed with a mixture mainly composed by the dry fraction (around 70%) originating from the squeezing step and a minor portion of the dried digestate (< 10%). The remaining fraction consists of green waste, either recirculated within the process or fed as new matrix to provide the most suitable porosity for air diffusion within the pile sent to composting. The daily compost production accounts for approximately 30 tonnes, corresponding to the 30% of the incoming OFMSW, which is comparable with the data reported by Zhang *et al*. (2010). During composting, the process losses occurring in the form of leachate and exhaust air, correspond to an overall mass degradation higher than 30%, which is consistent with previous studies and field experiences.

3.2. Mass balance for the German facility

The plant located in Germany basically treats the incoming waste via anaerobic digestion, whereas the composting stage can be regarded as a post-treatment for the digestate. The incoming OFMSW (100% w/w) is mixed with green waste (13% w/w) and pretreated to remove non-biodegradable fractions, while the remaining mixture is fed to two continuously operated anaerobic digesters. The pretreatment stage consists of a shredder, followed by a sieve and a magnetic separation. The latter splits the input mass flow into an oversieve, that is recirculated back to the shredder, and an undersieve proceeding within the treatment line to the digesters. In these reactors, the organic waste is dosed along with both the press water (~ 20%) originating from digestate centrifugation and the wastewater (~ 10%) that comes from the drainage of the external surfaces of the plant. The daily biogas production corresponds to an overall 13% anaerobic degradation of the mass fed to the digesters, whereas the digestate represents more than 70% of the incoming mixture. As any data was available on the centrifugation yields, it was assumed that the dried digestate accounted for the 40% of the produced digestate mass. Under this assumption, the produced compost represents approximately the 60% of the mass treated aerobically. The comparison of this facility with literature data referred to single aerobic processes highlights some differences in the share of products obtained from the German facility and, in particular, a greater compost production out of the incoming waste to the aerobic section. However, it should be considered that the substrate destined to composting is almost exclusively composed of dried digestate and that this material is, in turn, the result of the biological stabilization process occurred under anaerobic conditions. Although only partially complete, the anaerobic degradation contributes to the reduction of organic substances available within further biological processing, resulting in a lower weight loss of the mass processed aerobically.

3.3. Comparative assessment

The use of mass balances to study complex biological treatment facilities supported the comparative assessment of their performances and highlighted the influence of different biological process combination in the definition of the output mass flows. Both the studied facilities include an anaerobic as well as an aerobic stage, which are integrated in the Italian plant. Conversely in the German one they can be regarded as two steps of a sole processing line, where composting is applied as post-treatment to anaerobic digestion. In both facilities, a sieving pre-treatment precedes the anaerobic digestion stage, but the amount of waste removed as scraps in the Italian plant accounts for approximately 30% of the incoming OFMSW. This percentage drops to approximately 3% for the German facility, as a result of the continuous recirculation of the oversieve to the previous shredding unit. Although the content of impurities in the incoming waste highly influences the amount of scraps produced, the loss of organic waste along with removed scraps is likely to occur in the Italian plant. The mass of organic waste destined to anaerobic digestion is further reduced in the Italian plant: the liquid fraction from sieved OFMSW squeezing represents only the 28% of the input waste. Conversely, in the German plant almost 90% of the incoming OFMSW is destined to the anaerobic process. Anaerobic digestion yields are comparable, with specific biogas production, expressed as Nm^3/t_{VS}, slightly higher for the Italian plant due to both the lower organic load applied and the exceptionally higher retention time, which is approximately 75 days against the 14 days ensured in the German digesters. Although retention time in wet digesters is higher than in dry digestion systems, typical values vary indeed around 30 days. As for the aerobic stabilization section, although the mass flow destined to the treatment in the German plant is half that processed in the Italian plant, due to the different process scheme, the compost produced is 60% of the input mixture in the former plant and 36% in the latter. Such different results should be analysed with reference to the quality, in terms of biological stabilization, of the input mixture to composting. As already pointed out, the material addressed to the aerobic process in the German facility originates entirely from the anaerobic section, that provides its partial degradation. Conversely, in the Italian plant the greatest portion of the mixture fed to the composting system consists of the solid fraction originating from the pretreatment of the rough OFMSW, which is highly putrescible and, thus, much susceptible to the mass losses occurring during the aerobic biostabilization process.

4. Conclusion

In the present work mass balances were used to describe the performances of full-scale biological treatment plants, differently combining the anaerobic and the aerobic processes for the recovery of the organic fraction of municipal solid waste. Results pointed out that the process scheme does not influence significantly the production of biogas, which is linked to the proper operation of the anaerobic reactors as well as to the quality of the incoming waste. The latter aspect also affects the production of the scraps, consisting of the impurities removed from the waste over the treatment line. In this view, the analysis of the Italian facility pointed out that the amount of scraps originated in the pre-treatment step is much higher than the one produced from the same stage in the German facility. Notwithstanding the technological differences, it seems reasonable that the initial quality of the incoming waste is higher in the area served by the German plant. This evidence suggest the need to improve the quality of the separately collected organic waste destined to further recovery in Italy. Different consideration rose for the aerobic stabilization yields. In this case, the process scheme of the biological treatment facility affects both the amount of compost that is produced and the extent of process losses. A full-scale plant where composting is the post-treatment of the digestate originating from the anaerobic stage results in lower compost production and it can be a sustainable management option in those context where the market of compost is limited. Conversely, the integrated anaerobic/aerobic facilities would provide a more versatile treatment approach. In both cases, the highest level of purity of the rough OFMSW should be ensured to reduce the occurrence of non-biodegradable materials in the incoming waste flow destined to the anaerobic digestion. Although a pretreatment stage could enhance the quality of the incoming waste, extensive processing would determine the loss of a portion of organic matter that could be destined to the anaerobic treatment. Such condition determines, in turn, the increase of the amount of scraps to be disposed as well as a potential biogas loss with the consequent reduction of the energy production.

Acknowledgments

The authors wish to thank Nicola Flammia for his support in the collection and processing of the data referred to the German biological treatment facility.

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