Waste Management 50 (2016) 65–74

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Evaluation of a new pulping technology for pre-treating source-separated organic household waste prior to anaerobic digestion

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ARTICLE INFO

Article history:
Received 16 September 2015
Revised 29 January 2016
Accepted 29 January 2016
Available online 8 February 2016

Keywords:
Source-separated organic household waste
Pre-treatment
Mass balance
Biochemical methane potential
Hazardous substances

ABSTRACT

A new technology for pre-treating source-separated organic household waste prior to anaerobic digestion was assessed, and its performance was compared to existing alternative pre-treatment technologies. This pre-treatment technology is based on waste pulping with water, using a specially developed screw mechanism. The pre-treatment technology rejects more than 95% (wet weight) of non-biodegradable impurities in waste collected from households and generates biopulp ready for anaerobic digestion. Overall, 84–99% of biodegradable material (on a dry weight basis) in the waste was recovered in the biopulp. The biochemical methane potential for the biopulp was 469 ± 7 mL CH_4/g ash-free mass. Moreover, all Danish and European Union requirements regarding the content of hazardous substances in biomass intended for land application were fulfilled. Compared to other pre-treatment alternatives, the screw-pulping technology showed higher biodegradable material recovery, lower electricity consumption and comparable water consumption. The higher material recovery achieved with the technology was associated with greater transfer of nutrients (N and P), carbon (total and biogenic) but also heavy metals (except Pb) to the produced biomass. The data generated in this study could be used for the environmental assessment of the technology and thus help in selecting the best pre-treatment technology for source separated organic household waste.

1. Introduction

The European Union has set a recycling target of 50% by weight for municipal waste by 2020 (European Parliament, 2008). In Denmark, this target can only be reached if organic household waste is also recycled (Jacobsen et al., 2013). Recycling organic household waste by anaerobic digestion (AD) for biogas production requires source separation, which in fact is rarely perfect, as a proportion of unwanted materials, e.g. plastics, glass and metals, can often be found in the collected organic waste mass. In Denmark, organic household waste is currently disposed of via incineration with other residual waste. In regions where the source separation of organic household waste is implemented, impurities constitute between 5% and 23% on a wet weight basis (Petersen and Manokaran, 2012). These impurities can cause technical problems in the AD process and can lead to environmental impacts, for example from the land application of the process residue (digestate). This problem is usually addressed through the physical pre-treatment of the collected organic waste mass.

A general requirement in AD for pre-treating source-separated organic household waste (SSOHW) is to reject non-biodegradable impurities while having minimum biodegradable matter loss. For wet AD, the generated biomass should also be pumpable and should not contain large particles which could damage the system. If AD residues (digestate) are intended for use on land, contamination regarding content of hazardous substance content such as heavy metals (Pb, Cd, Cr, Cu, Ni, Zn, Hg) and organic pollutants[1] has to be in compliance with respective regulations. For biodegradable waste with animal origin, e.g. animal food waste, pathogen removal is also required (The European Parliament and the Council, 2002). Since the pathogen removal cannot be addressed with the physical pre-treatment methods, further hygienisation (i.e. heating at 70 °C for at least 1 h) of the generated biomass might be performed.

An investigation into the pre-treatment technologies typically applied in Denmark – screw press and disc screen – was conducted by Hansen et al. (2007). A screw press is a device that squeezes waste through a metal sieve, while a disc screen is a technique

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[1] Polycyclic Aromatic Hydrocarbons (PAH), Nonylphenole + Ethoxylates (NPE), Di-2-(ethyl-hexyl)-phthalate (DEPH). Linear alkylbenzene sulphonates (LAS).

http://dx.doi.org/10.1016/j.wasman.2016.01.042
0956-053X/

for separating smaller, denser particles from larger, lighter objects by passing organic waste through rotating discs set at certain distances. Hansen et al. (2007) found substantial organic losses going into the reject, i.e. up to 40% and 35% (wet weight) with the screw press and the disc screen, respectively, as well as problems with the quality of produced biomass. A better performing pre-treatment technique (material losses to the reject lower than 20% based on wet weight) exists in Sweden, the dispersion process presented in Bernstad et al. (2013). The method is based on powerful milling equipment commonly used within the pulp and paper industry. The drawbacks of the method are its complexity and high energy consumption.

Even though source separation has been implemented for years in several European states (e.g. Ministry for a Livable Austria, 2015) there is increasing interest in optimising the pre-treatment of SSOHW prior to anaerobic digestion, and so new technologies and techniques in this respect are emerging. Scientific data to evaluate these newly introduced treatment technologies, however, are largely missing. Technology assessments are based on detailed characterisations of process outputs, along with the further estimation of efficiencies regarding input material recovery and losses (Hansen et al., 2007; Bernstad et al., 2013). The transfer of carbon, nutrients and hazardous substances in the pre-treatment process, i.e. the distribution of initial quantities between the process outputs, as well as the overall quality of the biomass produced is obviously of importance when assessing the performance of the treatment. However, as stated by Carlsson et al. (2015), better biomass recovery in the pre-treatment stage may compromise the quality of the generated biomass, e.g. better energy and nutrient recovery may increase contamination of the biomass produced.

In the present study a new pre-treatment technology, based on waste pulping with water, was assessed. The pre-treatment technology generates biopulp intended for AD and a rejected waste fraction (hereafter called "reject") which is comprised mainly of non-biodegradable materials. The assessment included (1) the establishment of mass flows for the technology, including water consumption, (2) a determination of the quality of the biopulp produced, (3) a determination of the composition of the reject, including total content of biodegradable materials, (4) tracking transfer of substances of concern through the system and, finally, (5) a comparison of the technology performance with other pre-treatment alternatives including energy consumption. Three test series were performed in one year to quantify mass flows entering and leaving the system. For system flows that were accessible, the total solid (TS) and volatile solid (VS) contents were determined. Material losses to the reject, expressed as a percentage of the input material (wet weight), TS and VS, were also established, while biopulp quality was assessed by determining its biochemical methane potential (BMP) and other parameters. For the technology evaluation, literature-sourced data on SSOHW pre-treatment cases with the alternative technologies introduced earlier were collected, and a comparison for a range of parameters was then conducted.

2. Materials and methods

2.1. Technology description

The new technology investigated in this study was designed to process SSOHW prior to anaerobic digestion. The process involves waste pulping with water running through a specially developed screw mechanism. The screw induces mechanical motion in the waste mass, which in turn results in the dispersion (pulping) of biodegradable materials (e.g. food waste, paper), without tearing the non-biodegradable (e.g. plastics) materials into pieces. For the separation process, a perforated plate with a 6 mm hole is used. The two outputs from the system are biopulp (predominantly biodegradable solid biomass) and reject (mainly non-biodegradable impurities). The biopulp has to meet TS content specifications which are in the range of 15–18% of the wet weight. The waste is processed in batches and is accepted as collected from households (e.g. in waste bags), meaning no pre-shredding or bag opening is required (other pre-treatment technologies such as screw press, disc screen and dispersion processes do not accept bagged waste). This, in turn, decreases the chance that large non-biodegradable materials in incoming waste will be recovered in the biomass. Another advantage of the new technology is that it does not require the application of excessive pressure (unlike screw press treatments), which also helps to keep unwanted materials in the reject. Unlike disc screens, where the distribution of input waste between biomass and reject is highly dependent on the materials' physical proportions, the distribution undertaken by the pulping technology is more in line with the nature of the material (i.e. whether it is biodegradable or non-biodegradable).

Fig. 1 presents an overview of the pulping system. The pulping process occurs in a vertical tank – the pulper (1), in which the waste is mixed with water. After completing the pulping of one waste batch, the waste mixed with water is led to a separator unit (2) and the pulper is re-filled. In the separator, dissolved biomass is extracted through a perforated plate by applying a vacuum (3), thereby generating raw pulp. Raw pulp with the TS content meeting specifications (e.g., 15–18% of wet weight) is considered to be biopulp.

If the TS content of the raw pulp is not sufficient, the raw pulp is collected in the raw pulp buffer tank (4) to undergo dewatering (5), before it is fed into the biopulp storage tank (7). If TS content is sufficient, the raw pulp is fed into the storage tank directly. Water from dewatering the raw pulp is collected in a buffer tank for pulping water (6) and reused for pulping the next waste batch. The sequence runs depending on the TS content of the waste waiting for pulping, with a decision made by the operator based on former experiences of treating the same type of waste. Before biopulp leaves the pre-treatment facility the TS content of a biopulp sample from the storage tank is verified, and if necessary, adjusted by processing an extra waste batch.

The waste material remaining in the separator after raw pulp extraction is termed "reject". The reject is washed, drained and moved away on a conveyor belt for storage (8). Used water (the reject washing water) is recirculated for use in the next washing sequence. For recirculation, the water is collected in a separate buffer tank (9). It should be considered that most of the water recirculated in one processing sequence leaves the system as biopulp generated in the next sequence.

Any shortage of water for pulping and reject washing will be supplemented with clean water through the inlet into the system (10). No wastewater is generated during processing, and all of the system's contents are recovered in the biopulp.

The processing time and the waste quantity per batch depend on waste quality, namely how free from impurities the waste is, and how much reject has to be handled. For SSOHW, 2.2–3.5 tonnes of waste can be treated per batch, each batch taking from 26 to 34 min. Clean water consumption per tonne of SSOHW treated is not fixed and varies depending on the amount of reject already generated and the amount of used water that is available.

2.2. Waste pulping test procedure

SSOHW provided by a Danish waste management company was processed at a pulping facility. The test was split into three series run in June, August and November of 2014. For each of the three test series about 6 tonnes of SSOHW was provided. Each test series included three process batches (of ca. 2 tonnes each) performed