Waste Management 47 (2016) 78–83

Contents lists available at ScienceDirect

Waste Management

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

Extraction of medium chain fatty acids from organic municipal waste and subsequent production of bio-based fuels

Jan Kannengiesser *, Kaori Sakaguchi-Söder, Timo Mrukwia, Johannes Jager, Liselotte Schebek

Technische Universität Darmstadt, Institute IWAR, Faculty of Civil and Environmental Engineering, Franziska-Braun-Strasse 7, 64287 Darmstadt, Germany

ARTICLE INFO

Article history:
Received 30 January 2015
Revised 22 May 2015
Accepted 26 May 2015

Keywords:
Bio-waste
Bio-based fuel
Percolation
Chain elongation
Composting

ABSTRACT

This paper provides an overview on investigations for a new technology to generate bio-based fuel additives from bio-waste. The investigations are taking place at the composting plant in Darmstadt–Kranichstein (Germany). The aim is to explore the potential of bio-waste as feedstock in producing different bio-based products (or bio-based fuels). For this investigation, a facultative anaerobic process is to be integrated into the normal aerobic waste treatment process for composting. The bio-waste is to be treated in four steps to produce biofuels. The first step is the facultative anaerobic treatment of the waste in a rotting box namely percolate to generate a fatty-acid rich liquid fraction. The Hydrolysis takes place in the rotting box during the waste treatment. The organic compounds are then dissolved and transferred into the waste liquid phase. Browne et al. (2013) describes the hydrolysis as an enzymatically degradation of high solid substrates to soluble products which are further degraded to volatile fatty acids (VFA). This is confirmed by analytical tests done on the liquid fraction. After the percolation, volatile and medium chain fatty acids are found in the liquid phase. Concentrations of fatty acids between 8.0 and 31.5 were detected depending on the nature of the input material. In the second step, a fermentation process will be initiated to produce additional fatty acids. Existing microorganism mass is activated to degrade the organic components that are still remaining in the percolate. After fermentation the quantity of fatty acids in four investigated reactors increased 3–5 times. While fermentation mainly non-polar fatty acids (pentanoic to octanoic acid) are build. Next to the fermentation process, a chain-elongation step is arranged by adding ethanol to the fatty acid rich percolate. While these investigations a chain-elongation of mainly fatty acids with pair numbers of carbon atoms (acetate, butanoic and hexanoic acid) are demonstrated. After these three pre-treatments, the percolate is brought to a refinery to extract the non-polar fatty acids using bio-diesel, which was generated from used kitchen oil at the refinery. The extraction tests in the lab have proved that the efficiency of the liquid–liquid-extraction is directly linked with the chain length and polarity of the fatty acids. By using a non-polar bio-diesel mainly the non-polar fatty acids, like pentanoic to octanoic acid, are extracted. After extraction, the bio-diesel enriched with the fatty acids is esterified. As a result bio-diesel with a lower viscosity than usual is produced. The fatty acids remaining in the percolate after the extraction can be used in another fermentation process to generate biogas.

1. Introduction

With the growing world population, more food and energy will be needed to guarantee an adequate standard of living for all people around the world. Currently, not only food but also energy is produced from agricultural products. In 2020 about 10% of the fuel consumption should be provided from renewable resources (European Comission, 2010). To reach this aim, about 17% of the agricultural land has to be used for the production of energy crops. It is currently not possible to meet this demand only by European crops. Since this need cannot be supported by Europe alone and imports must therefore ensure an appropriate compensation. This problem will lead to a competition between food and fuel production, by using renewable resources. Which will have a result of three billion people suffering from hunger and malnutrition (Burdick and Waskow, 2009).

To ease this conflict, existing resources have to be used more efficiently and the recovery of secondary resources from waste has to be improved as well. One possibility to improve the resource recovery from waste is discussed in this paper.

* Corresponding author. Tel.: +49 6151162848; fax: +49 6151163739.
E-mail address: j.kannengiesser@iwar.tu-darmstadt.de (J. Kannengiesser).

http://dx.doi.org/10.1016/j.wasman.2015.05.030

More than 7.6 million tonnes of bio-waste in Germany are treated year by year to generate compost, which can be used as fertilizer in agriculture BMUB (2014). Further, only 5.4 million tonnes of bio-waste were used in biogas plants to produce biogas for heat and electricity generation of BMUB (2014). The new idea of using biodegradable waste is to combine a composting plant with a facultative anaerobic treatment step (Hoffmann, 2012). The organic acids carry the main part of the energy content of biomass in an early stage of anaerobic digestion process and are easy to transfer into liquid products by further biorefinery steps. After the extraction of organic acids, the residual waste can be transported to the composting plant to generate high quality compost.

2. Materials and methods

All investigations are based on the biological waste of Darmstadt, which is collected from private households and treated at the composting facility in Darmstadt (Kranichstein). In this chapter the composition and the treatment process of the organic material will be described. The following flow chart shows the treatment process at the composting facility (see Fig. 1).

The new approach of these investigations is an integration of a solid–liquid separation into an existing composting facility (Hoffmann, 2012). The delivered waste at the facility is first mixed. Then a sample of 1 wt% is sorted to analyze the composition of the waste. Afterwards the mixed waste is shredded and brought to a rotting box, where the solid–liquid separation takes place. For the production of bio-based products and bio-based fuels only the liquid phase is used. The solid bio-waste phase is brought to another rotting box, where aerobic degradation of the waste takes place and compost is produced. After the solid–liquid-extraction in the rotting box, the liquid bio-waste phase is treated at anaerobic conditions to degrade the organic materials to carboxylic acids (acetate to octanoic acid). Another treatment step after the digestion of the liquid phase is used to produce medium chain fatty acids in the liquid bio-waste phase. By adding, at anaerobic conditions, ethanol to the liquid substrate, a chain elongation process of the dissolved fatty acids is initiated. The result of this ethanol maturation is the production of medium chain fatty acids, like pentanoic to octanoic acid.

Afterwards, the liquid substrate is brought to a bio-refinery, where a liquid–liquid-extraction with bio-diesel as solvent takes place and the non-polar fatty acids are extracted. At the bio-refinery, the bio-diesel enriched with non-polar fatty acids is transesterified (Leung et al., 2010; Karmee et al., 2015) or treated by electrosyntheses to produce esters, olefins and alcohols (Wagner, 2012). The remaining liquid substrate can be used for digestion to produce biogas. A re-use of the waste water after digestion at the solid–liquid separation is possible.

In the following sub-chapters the treatment process and methods are described in more detail.

2.1. Composition of organic waste in Darmstadt

A sorting process was used to determine the composition of the biological waste delivered to the composting facility. The reason for the waste sorting is to have an idea about the properties of the different waste fractions. For the extraction of fatty acids and the generation of bio-based fuels, the waste has to be easy degradable. The generation of fatty acids from poorly degradable bio-waste will take a long time or will need a special treatment, which lead to higher energy consumption.

While sorting, the waste was divided into different fractions, like kitchen waste and vegetable waste, which belong to easy degradable substances. Other fractions, like green waste, plastics and residual waste, which belong to poorly degradable or non-degradable substances, were also recorded. All these fractions were put up together into three main fractions, namely, (1) "green waste" (poorly degradable), which consists of garden waste from private households, (2) "food waste" (easy degradable), which consists of the fraction of kitchen waste and vegetable waste and (3) "unwanted" containing the fraction of plastics and residual waste, which are not to be declared as bio-waste.

2.2. The percolation and fermentation process

A modified rotting box is installed at the composting facility in Darmstadt. Organic waste collected and shredded is first treated in the rotting box. Water is supplied continuously in the box and the leachate of the waste is collected and recirculated in the system to enrich the water-soluble organic components in the liquid phase. While the feedstock is soaked through this percolation process inside of the rotting box, the pre-treatment process (i.e. hydrolysis and acidification) takes place in the box. The rotting box is operated under facultative anaerobic conditions to avoid oxidation as well as methanation reactions. A basic scheme of the rotting box is shown in Fig. 2.

The organic-rich bulk liquid is collected periodically from the rotting box and stored in an intermediate bulk container (IBC) under certain conditions to ensure fermentation. During the fermentation process, fatty acids are produced (Levy et al., 1981a, b; Jiang et al., 2013). The bulk liquid is analyzed and the production of fatty acids is monitored. Particularly, C4-8 fatty acids, namely, butanoic, pentanoic, hexanoic, heptanoic and octanoic acid will be analyzed by gas chromatography–mass spectrometry (GC–MS).

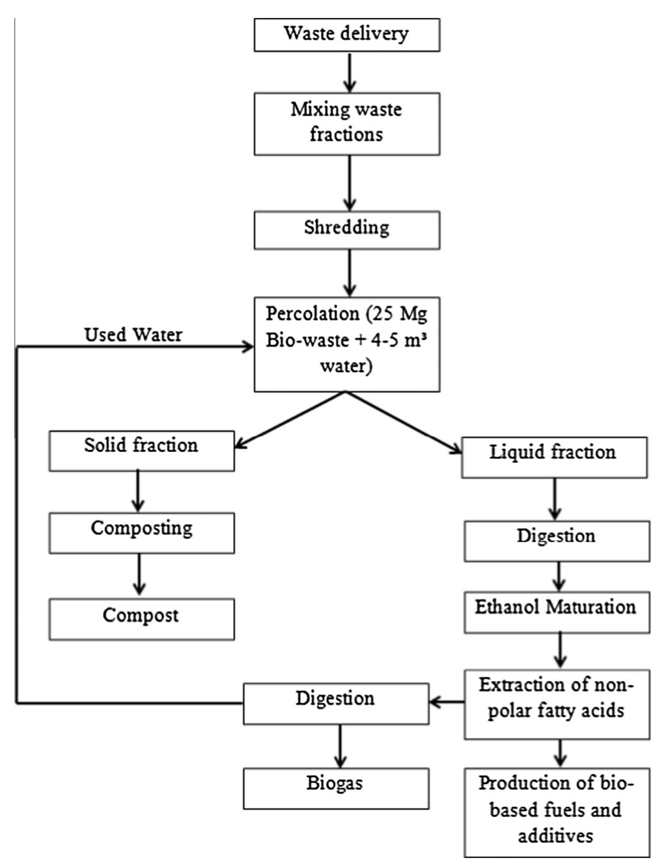

Fig. 1. Treatment process at the composting facility.