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Influence of operating conditions for volatile fatty acids enrichment as a first step for polyhydroxyalkanoate production on a municipal waste water treatment plant

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HIGHLIGHTS

- Different flows of a waste water treatment plant were tested as raw material.
- Primary sludge yielded the highest amount of VFA and stable VFA composition.
- Best operating conditions are: 30 °C, pH 7, retention time 4 d and 25% withdrawal.
- Semi-continuous operation method yielded better results than batch operation.
- Stable VFA composition could be reached.

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ABSTRACT

This work describes the generation of volatile fatty acids (VFAs) as the first step of the polyhydroxyalkanoate (PHA) production cycle. Therefore four different substrates from a municipal waste water treatment plant (WWTP) were investigated regarding high VFA production and stable VFA composition. Due to its highest VFA yield primary sludge was used as substrate to test a series of operating conditions (temperature, pH, retention time (RT) and withdrawal (WD)) in order to find suitable conditions for a stable VFA production. The results demonstrated that although the substrate primary sludge differs in its consistence a stable composition of VFA could be achieved. Experiments with a semi-continuous reactor operation showed that a short RT of 4 d and a small WD of 25% at pH = 6 and around 30 °C is preferable for high VFA mass flow (MF = 1913 $mg_{VFA}/(L\,d)$) and a stable VFA composition.

1. Introduction

Common plastic is derived from petrochemicals based on the limited natural resource petroleum. This is causing serious environmental problems. Beside the exploitation of natural resources the use of plastic is responsible for major waste problems as common plastic is non- or poor biodegradable (UNEP, 2009).

Biopolymers present a possible alternative to common plastics. As they are fully biodegradable (Jendrossek and Handrick, 2002; Choi et al., 2004) their use not only allows the preservation of limited resources, but also suits the idea of sustainability.

Beside other polymers polyhydroxyalkanoates (PHA), which are biodegradable polyesters accumulated by bacteria under nutrient limited conditions (Nikodinovic-Runic et al., 2013), are a source for bioplastic production. More than 150 component parts of PHA have been identified so far (Cavalheiro et al., 2009). The possibility for chemical modification of PHA provide a wide range of material properties and an even wider range of use (Zinn and Witholt, 2005; Akaraonye et al., 2010). However, the main raw material for the biopolymer production are starchy plants like maize (Steinbuechel, 2005), constituting the disadvantages of high land consumption, diminishing food resources as well as problems like leaching of nutrients, input of pesticide and soil erosion (Faulstich and Greiff, 2007). Additionally, bioplastic production is rather expensive, with up to 38% of the costs accounting for the raw material (Lee and Choi, 1997; Choi and Lee, 1999).

So far, municipal waste water treatment plants (WWTP) as alternative raw material and biomass source for the PHA production have not been widely investigated, although they offer the opportunity to compensate the disadvantages of the common PHA production using starchy plants.

The biological process of PHA production takes place in two steps, which composes the production of volatile fatty acids (VFA) in an anaerobic process and finally the PHA production in

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an aerobic process (see also Fig. 1). In contrast to Bengtsson et al. (2008b) and Morgan-Sagastume et al. (2013) the PHA production process described in this work is designed as a side stream process of a municipal WWTP and does not include the treatment of waste water. Therefore the whole process must consider the polymer production only.

Chakravarty et al. (2010) showed the possibility to use ice-cream waste water as alternative source material for the VFA production while Chua et al. (2003) investigatde the effect of pH, sludge-retention time (RT) and acetate concentration on the PHA production from municipal waste water. Diverse authors (Chua and Yu, 1999; Dionisi et al., 2004; Lemos et al., 2006; Reddy et al., 2008) stated that there is a general possibility to produce PHA from activated sludge and Beun et al. (2000) showed that industrial waste water provides a low cost alternative substrate for VFA production.

In many of the research projects on PHA production, synthetic waste water was used to gain knowledge about one part of the PHA production or the production's operating conditions (Albuquerque et al., 2007; Albuquerque et al., 2010; Albuquerque et al., 2011; Bengtsson, 2009; Bengtsson et al., 2010; Choi and Lee, 1997; Dionisi et al., 2005). In contrast, the objective of this research project is to find the most suitable raw material and all operating conditions for the VFA production process using only material flows of a WWTP.

This work focuses on the first step of PHA production, the generation of VFAs. At first different raw materials of a municipal WWTP to produce VFAs were observed. Afterwards the influence of operating conditions (temperature, pH, retention time (RT) and withdrawal (WD)) and reactor operation method on VFA production were investigated. Another concern was, how the tested operating conditions or the diversity of the used material flows of a WWTP influence the VFA composition and consequently the kind of PHA produced. As there is a variation in the composition of the used material flows (sludges) of a WWTP, it is of particular importance to observe their influence on VFA production and composition.

2. Methods

2.1. Experimental set-up

The overall production process to produce biopolymers from municipal waste water is displayed in Fig. 1. This work covers "(1): Acidogenic fermentation" only. Therefore anaerobic reactors of different sizes (4 L, 15 L) were operated as batch reactors or as semi-continuous reactors. While the batch operation is defined as a one-time substrate filling at the beginning of the experiment with no withdrawal and refill during the test, a semi-continuously operation method allows to introduce and withdraw substrate to the reactor. Semi-continuously operation means that the amount of substrate, which has to be changed is withdrawn and refilled at once.

There was no sedimentation or biomass recirculation in all tests. Therefore the hydraulic retention time equals the sludge age and both will be referred hereinafter as RT.

As most of the results influence the following tests, a chronological test order was implemented as follows:

1. Selection of raw material.
2. Evaluation of operating conditions including.

   (a) Selection of suitable pH-level.
   (b) Evaluation of a RT range.
   (c) Selection of a suitable combination of RT and withdrawal (WD).

The raw material selection has the highest priority. Therefore it was investigated at first. The optimisation of the operating conditions for the VFA production was examined afterwards with the most appropriate raw material found.

2.1.1. Selection of raw material

For raw material selection continuously stirred batch reactors with a volume of 4 L were used. Four different sludges, namely primary sludge (average total solid (aTS) = 43 g/L), excess sludge (aTS = 10 g/L), a one to one mixture of primary- and digested sludge (aTS = 37.5 g/L) and a one to one mixture of excess- and digested sludge (aTS = 21 g/L) from a municipal WWTP were analysed. Thereby digested sludge was only used as inoculum for the anaerobic process in order to find out, if it could accelerate the process. All named sludges were investigated under four different conditions: pH controlled at pH = 6, without pH-control and each at around 20 °C or around 30 °C reactor temperature. In summary 16 different tests were performed. The reactors were filled at the beginning of the experiments and samples of 50 mL were retrieved every day to determine the VFA concentration and composition. To achieve the selected temperature the reactors were situated in temperature-controlled rooms. For pH-controlled tests, the pH-value was measured by a mobile pH meter (WTW pH340i) and adjusted with NaOH by hand twice a day. The test duration for all experiments was 18–20 d. A sample of all tested sludges was taken before and after the tests to determine COD, TKN and total P.

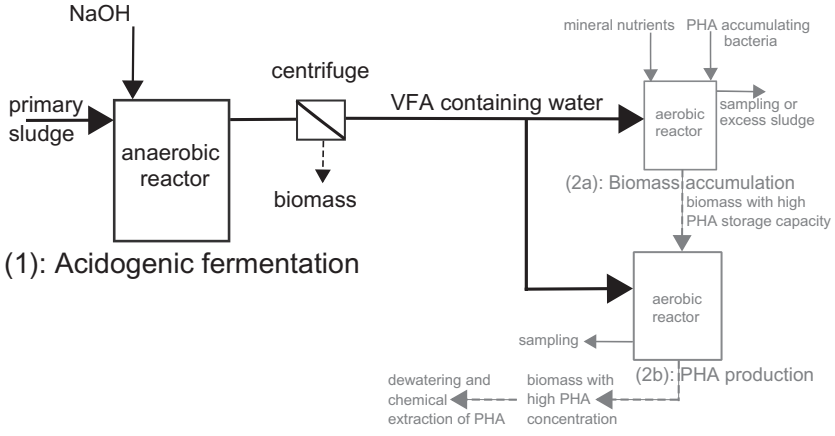

Fig. 1. Experimental set-up for the biopolymer production from waste water.