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Effect of ultrasound amplitude and reaction time on the anaerobic fermentation of chicken manure for biogas production

Patrick Braeutigam*, Marcus Franke, Bernd Ondruschka

Institute for Technical Chemistry and Environmental Chemistry, Friedrich-Schiller-University, Lessingstrasse 12, D-07743 Jena, Germany

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A B S T R A C T

In this study, a biological waste material, chicken manure, was sonicated in aqueous solution at 24 kHz. The effect of ultrasound amplitude and reaction time were investigated in terms of biogas yield and methane content. Best results were found at high amplitudes and high reaction times by trend, where the biogas yield could be increased up to 41% (278 NL/kg ODM (untreated), 393 NL/kg ODM) with a required energy input of 0.08–0.25 kWh/kg ODM (organic dry matter). Moreover, the methane content could be increased in most instances, at best, from 66.9% (untreated) to 70.4%. Consequently, the use of ultrasound could increase the total methane yield up to 46% (186 NL/kg ODM (untreated) to 271 NL/kg ODM (sonicated)). In this study, the correlation of the biogas yield with SCOD and particle size were investigated and the effect of ultrasonic waves on the nutrient relationship (C:N:P) was evaluated, too. At least, comparison of energy was done, where it could be shown that the ultrasound disintegration leads to a significant increase in the net energy yield with respect to the conventional biological hydrolysis.

1. Introduction

The sustainable production of energy based on renewable sources is a field of high socio-economic interest, due to the limited fossil resources. The production of biogas as a green technology is a base loadable technology in contrast to other renewable energy production processes like photovoltaic or wind power [1]. In general, energy crops or biological waste materials were used as substrates [2,3].

The production of biogas is a complex biotechnological process that can be divided into four reaction steps based on each other (Fig. 1). First, the polymeric biomass components are digested by hydrolysis, to release organic constituents. Therefore, the educts (fats, proteins, carbohydrates) are broken by enzymes in soluble oligomers and monomers (peptides, amino acids, fatty acids, glycerol, oligo- and monosaccharides). In acidogenesis this substances are converted to hydrogen, CO_2, organic acids, acetic acid, and alcohols. At best, this reaction step leads to acetic acid, since it can be converted directly by methanogenic archaea (methanogenesis). However, this depends on several factors, e.g. species-specific metabolic pathways and hydrogen partial pressure have a significant influence on the reaction products. If hydrogen partial pressure is high, usually higher organic acids such as propionic acid were generated. In acetogenesis

* *Corresponding author*. Tel.: +49 3641 948458; fax: +49 3641 948402.
E-mail address: patrick.braeutigam@uni-jena.de (P. Braeutigam).
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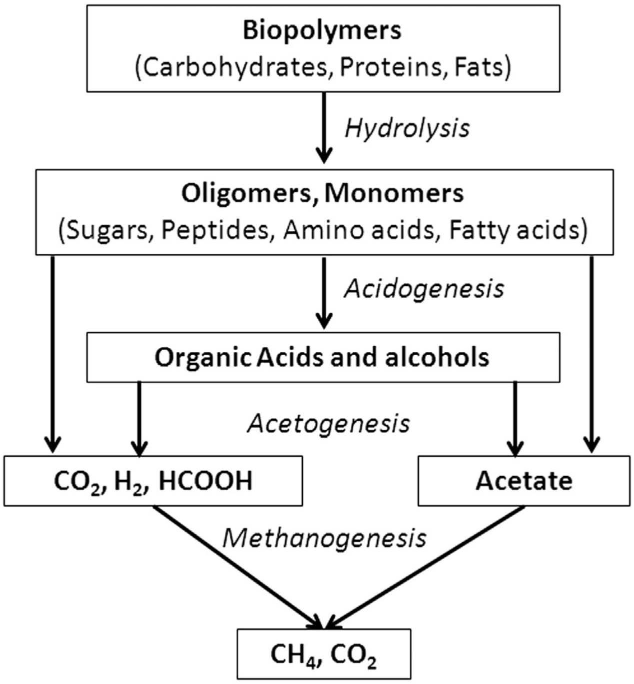

Fig. 1 – Steps of the biogas production process.

these intermediates are converted to acetic acid, which can be converted finally to biogas (methanogenesis) [4].

Biogas is the name of the gas mixture, which is produced by anaerobic digestion. It consists mainly of CH_4, CO_2, and H_2S. After cleaning, it is usually inducted to a combined heat and power plant (CHP) to generate electricity and heat [4]. The resulting electricity is applied for electricity grid and heat is often used to cover the own heating requirements for the fermenter. The fraction of the biomass that cannot be degraded, the digestate, is dewatered with flocculants or separators and partly used as fertilizers in agriculture [4].

The hydrolysis is an important reaction step because it determines the fraction of biomass, which is bioavailable in the process. Therefore, non-bioavailable biomass thus makes no share for biogas production and leads to higher mass of digestate, subsequent follow-up costs (e.g., disposal, landfill) and to lower profit expectations due to insufficient utilization of the energy content of the substrates. Conventional, the hydrolysis is conducted microbiologically. This leads to high retention times and low degree of degradation and therefore to a lower bioavailability of the biomass and higher mass of digestate, due to pH-values optimized for the methanogenic phase [5]. An optimal use of biomass energy can either be generated by longer residence time in the fermenter or by special disintegration methods. In general, disintegration methods can be divided into mechanical (e.g. ball mill, ultrasound, high-pressure homogenizer), chemical (e.g. thermochemical hydrolysis, alkaline/acidic hydrolysis, wet oxidation) and thermal processes, with method-specific advantages and disadvantages [6].

In this study the acoustic cavitation induced disintegration of chicken manure was investigated. Cavitation processes for disintegration can be easily adjusted to different volume flows, require low space, and show high operational safety and stability against contaminants in comparison with other disintegration methods [6]. Cavitation can be generated in different ways (acoustic (ultrasound), hydrodynamic, optical, particle induced) and is defined as the formation, growth and subsequent collapse of bubbles in liquids [7]. In the collapse phase high shear forces and microjets are generated [8,9], leading to diminishing the particle size of the biomass substrates and/or reduction of the chain length of polymers [10] and therefore to an increased bioavailability of the substrates. Currently, there exist some works concerning on the use of cavitation in biogas processes, using different substrates and ultrasound systems [11,12], but there are less information of the correlation of typical ultrasound parameters on biogas yield and methane content. Therefore, in this study the effect of ultrasound amplitude and reaction time was investigated in terms of biogas yield, methane content, nutrient relationship (solved) and the disintegration energy balance.

2. Materials and methods

All experiments were conducted in a cylindrical glass reactor (volume: 300 mL), equipped with a sonotrode (S14L2D, tip diameter: 14 mm, titanium, Hielscher Ultrasonics, Teltow, (Germany)) and an ultrasound generator (UP200S, 200 W, 24 kHz, Hielscher Ultrasonics, Teltow (Germany)) at room temperature. Therefore, 200 mL of an aqueous chicken manure mixture was prepared (5% DM (dry matter)) and sonicated at different amplitudes and reaction times, where the energy required was recorded.

The DM of the samples was identified by means of a moisture analyzer (MA 40, Sartorius, Göttingen (Germany)). The ODM (organic dry matter) of the DM samples was determined by the weight loss after the thermal treatment at 550 °C for 2 h (N11/H, Nabertherm, Lilienthal (Germany)).

The biogas yield of each experiment was measured by fermentation tests (triplicate determination). Therefore, ca. 20 g of aqueous chicken manure mixture together with 200 g of digested sludge were filled in gas proofed batch reactor and stirred with 110 rpm at 38 °C under nitrogen atmosphere (anaerobic milieu). The produced amount of gas was detected by eudiometers one time a day and the methane content by a gas analyzer (COMBIMASS GA-m, Binder, Ulm (Germany)).

The detection of particle size and specific surface was done in aqueous solution with a laser diffraction particle size analyzer (LS 230, 0.04–2000 μm, Beckman Coulter, Krefeld (Germany).

For detection of SCOD (solved chemical oxygen demand), DOC (dissolved organic carbon), SN_b (solved nitrogen bound) and $SP\text{-}PO_4$ (solved phosphate) the samples were filtered (syringe filter, 0.45 μm, cellulose acetate, VWR International, Darmstadt (Germany)) an analyzed by cuvette tests (LCK 014, LCK 381, LCK 338, LCK 350, Hach-Lange, Düsseldorf (Germany)) with the help of a high temperature thermostat (HT 200S, Hach-Lange, Düsseldorf (Germany)) and a spectrophotometer (DR 2800, Hach-Lange, Düsseldorf (Germany)).

The results were evaluated with the help of statistical software (Design Expert V8, Stat-Ease, Minneapolis (USA)).