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Production of Biogas from Anaerobic Co-digestion of Biosolids from Wastewater Treatment

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

With a growing global population and the constant striving for prosperity, comes a growing demand for energy. Biogas and its upgrading to biomethane are prosperous and sustainable energy sources that even allow the use of the natural gas infrastructure. Biogas production using different bacterial cultures for wastewater treatment can be decentralized and without high costs. This aim of this research is focused on the co-digestion of wastewater biosolids and bacteria from a commercial activated sludge reactor, and customary bacteria used for the treatment of septic systems sludge. The research was performed with a designed laboratory anaerobic fermentation system at 35-40°C (95-104°F).

The biomass-gas turnover rate is on average 170 l/kg for activated sludge reactor bacteria and 100 l/kg septic system bio bacteria.

The application of wastewater treatment bacteria as basis for anaerobic fermentation can be considered beneficial for biogas production within wastewater treatment plants.

Keywords: Anaerobic digestion; bacteria; biogas; energy production; fermentation wastewater treatment.

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1. INTRODUCTION

Biogas is one of the most prosperous alternatives to natural gas. According to the American Biogas Council, there are more than 2.200 production sites in the US. More than half of them are anaerobic digester on water resource recovery facilities. Landfill gas projects with about 25% of the total amount are the second largest group followed by anaerobic digesters on farms and stand-alone systems to digest food waste [1]. The leading role in the world's biogas production is hold by Europe with roughly 31 billion cubic meters produced in 2019 [2]. Based on the Institut für Energie- und Umweltforschung Heidelberg (ifeu) European Countries operate in 2019 over 20,000 biogas plants, producing approximately 18 billion cubic meters (bcm) of natural gas equivalent, and a target of 35 bcm for 2030 [3].

The substrate potential for biogas production is particularly high with animal manure, livestock effluents, fruit and vegetable by-products and energy crops. Together there was an estimated overall production volume of $10{,}4 \cdot 10^{10}$ m³/year for 2019 [4].

Biogas consists of various components; the two major ingredients are methane (50-80% by volume) and carbon dioxide (20-50% by volume) [5]. When removing carbon dioxide, biomethane - the equivalent to natural gas - remains. According to the International Energy Agency (IEA), less than 20% of the biogas was upgraded to biomethane. In 2018, the main biogas consumption by end use were power generation, co-generation, and heat for buildings [6,7].

Nevertheless, biomethane has many advantages in comparison to conventional methane. It is counted as a renewable energy source and emits less pollution than diesel or gasoline, when combusted. Moreover, it can be produced from locally made biogas and doesn't have to be transported as far as natural gas. By-products of the biomethane manufacturing can be used as sustainable fertilizer. With the opportunity to feed the biomethane into the conventional gas infrastructure, the gas can be used in geographically scattered facilities [8].

Biogas and biomethane are expected to help decarbonizing parts of the energy system which can't be reached by low-carbon electricity. Due to their plant's independence from outer circumstances, they can support the rise of wind and solar systems. Therefore, the demand for biofuels is expected to be growing permanently [4].

To substitute the full demand for natural gas with biogas, research on several production methods must continue. This research work focuses on the production of biogas as a fermentation by-product using biosolids generated in a wastewater treatment plant. Bacteria from a commercial activated sludge reactor and commercially available bacteria used to upgrade residential septic systems were used as inoculant.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Laboratory Benchtop Anaerobic Fermentation system

For producing and capturing the methane, a laboratory benchtop anaerobic fermentation system (LBAF-system) is applied. The required hardware and barrier fluid used as well as the fermentation set up were developed by Dölle and Hughes [9].

2.1.2 Analytical Evaluation

For the analytic evaluation, a Denver Instrument SI-234 balance, a Milwaukee MW102 portable pH- thermometer portable and a Thelco drying oven (set to 105°C (221°F) as well as a Fisher Scientific Thermolyne 1.3 l (0.04 cuft) Muffle furnace set to 525°C (437°F) are being utilized.

2.1.3 Biomass suspension

For the first experimental setup, Biosolids and Activated Sludge Reactor (ASR) bacteria are merged in a 9:1 ratio based on a total suspension weight of 300g. This ratio ensures good mixing during the fermentation based on previous experience. ASR bacteria were obtained from a commercial activated sludge reactor at a nearby commercial Wastewater Treatment Plant (WWTP). Biosolids were obtained from a Sequential Batch Reactor (SBR) located the Village of Minoa, NY WWTP. The second setup used a suspension consists of 0,67% commercially available Septic Tank-Treatment (STT) bacteria and 99,33% biosolids by dry weight based on a total suspension weight of 300g.

2.2 Methods

The LBAF System as shown in Fig. 1. was adopted and installed as described by Doelle and Hughes from a previous study [9].

The fermentation process is operated on a temperature of 35-40°C (95-104°F). Therefore, the Erlenmeyer flask (3), which contains the biomass suspension (11), is kept in a water bath (12) inside a heating vessel (2). A magnetic stirrer is used to homogenize the suspension (11). Both, water bath (12) and stirrer, are operated by a magnetic heating plate (1). For capturing and measuring the emerged biogas (13), the flask (3) is linked to a measuring cylinder (9) filled with barrier fluid (14). Throughout displacement of the barrier fluid (14) in the cylinder (9), the volume of biogas (13) can be detected.

Cylinder (9) and Flask (3) are connected via a Polyvinylchloride (PVC) hose (5). To prevent a loss of biogas (13), a rubber stopper (4) is plugged into the flask (3) and sealed with tape. The PVC-hose (5) is connected to a shut-off valve and a tee (7) that enables controlling the level of barrier fluid in the cylinder. The tee's (7) third opening is connected to another shut off valve (8) and a three-way rubber suction ball (15). With this component, the gas in- and outlet can be controlled. The barrier fluid (14) is stored in a barrier fluid reservoir (10), which is underneath the cylinder's (9) aperture.

Reading accuracy of the produced biogas shall be within a tolerance of ±1ml.

2.3 Testing Procedures

The procedures to determine the Total Solids Content (TSC), the Total Ash Content (TAC) and the Reactive Biomass (RB) as well as pH are described in the following section. The tests for TSC and TAC are run in triplicate.

For the TSC-analysis, a sample of 40-50 g is given into an aluminum sample tray and dried at 105°C (221°F) for 24h. In order to obtain the TSC- value, the mass of dried product is divided by the mass of the undried material. The value is expressed as a percentage. It is estimated that the weight loss is caused by moisture evaporating. The used method is modified and based on TAPPI test T412 om-06 "Moisture in pulp, paper and paperboard" [10] For performing the TCA-test, the remaining dry material is combusted in a 525°C (977°F) muffle furnace for about 4 hours. The TCA-test is based on a modified TAPPI T211 om-02 "Ash in wood, pulp, paper and paperboard: Combustion at 525°C" [11]. For the TAC, the mass of the ash is divided by the mass of the dried material.

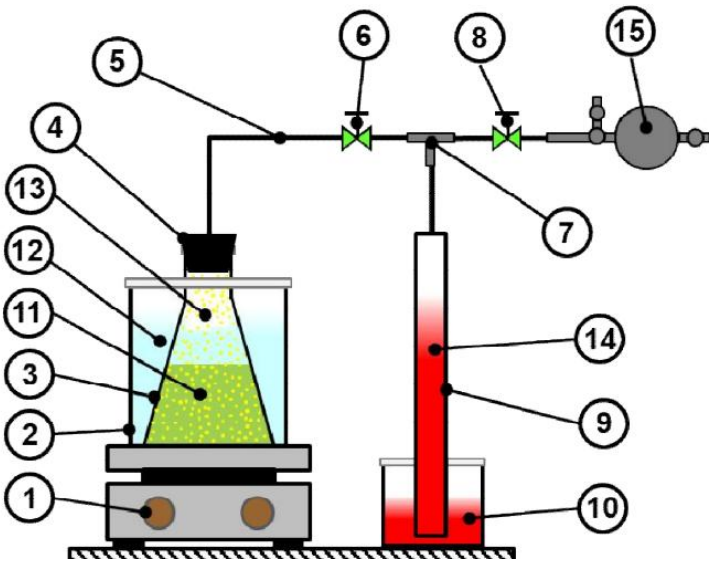

Fig. 1. Laboratory Benchtop Anaerobic Fermentation system: 1) Digital heating stirring hot plate, 2) Heating vessel, 3) Fermentation vessel, 4) Rubber stopper, 5) PVC hose, 6,8) Shut-off valve, 7) Tee, 9) Barrier fluid displacement vessel, 10) Barrier fluid reservoir, 11) Biomass suspension, 12) Heated water, 13) Biogas, 14) Barrier fluid, 15) 3-way rubber suction ball [9]

Equation 1 is used to calculate RB as a function of TSC and TAC.

$$RB(TSC,TAC) = \left(TSC_{feed} \cdot \left(1 - TAC_{feed}\right) - TSC \cdot (1 - TAC)\right) \cdot mass_{feed} \quad (1)$$

RB is expressed in weight units and shows how much biomass was converted. The pH-value was tested with a Milwaukee MW102 portable pH-thermometer.

2.4 Material Preparation

For the fermentation 30 g (1.06oz) ASR-Bacteria were mixed with 270 g (9.52 oz) of and introduced into the experimental setup. The second setup contains 2 g (0.07 oz) SST-Bacteria and 298 g (10.51 oz) of BS. Both fermentation setups are done in duplicate.

3. RESULTS AND DISCUSSION

After a fermentation period of 206 hours, the experiment was stopped. Both, values for TSC/TAC and VAC and pH, before and after the digestion process, as well as the generated biogas were measured.

3.1 Anaerobic Digestion of SST-Bacteria and Biosolids

The average biogas produced by both setups is 233 ml. Setup 1 reaches an overall biogas production of 263 ml and setup 2 produces 202 ml. Thus, average production rates of 1.28 ml/h (1) and 0.98 ml/h (2) are achieved. Nevertheless, the production rate is not consistent but declines over time. Fig. 2 shows the development of the biogas the production in both setups during the fermentation time.

The pH measure with the feed mixture is 8.02. After 206 hours fermentation a pH of 7.10 for biomass 1 and 6.95 for biomass 2 (i.e., 7.03 on average) resulted.

TSC decreases from 2.48% (feed) to 1.82% (1) and 1.77% (2) or respectively 1.80% in average.

The Total Ash Content of the fed biomass is 28.58%. It remains relatively constant with an average value of 27.04% after fermentation (setup 1: 28.23%, setup 2: 25.86%).

Following, the RB can be calculated with equation (1). In the first setup, 1.40g (0.05oz) of the biomass has reacted during the production period. In relation to the amount of produced biogas (263ml), a turnover rate of 0.19 l/g or 190 l/kg RC can be determined. The second setup has a reactive biomass of 1.37g and a turnover rate of 0.15g/l or 150l/kg RC. This results in an average RB of 1.38 g and turnover rate of 0.17 l/g or 170 l/kg of RC.

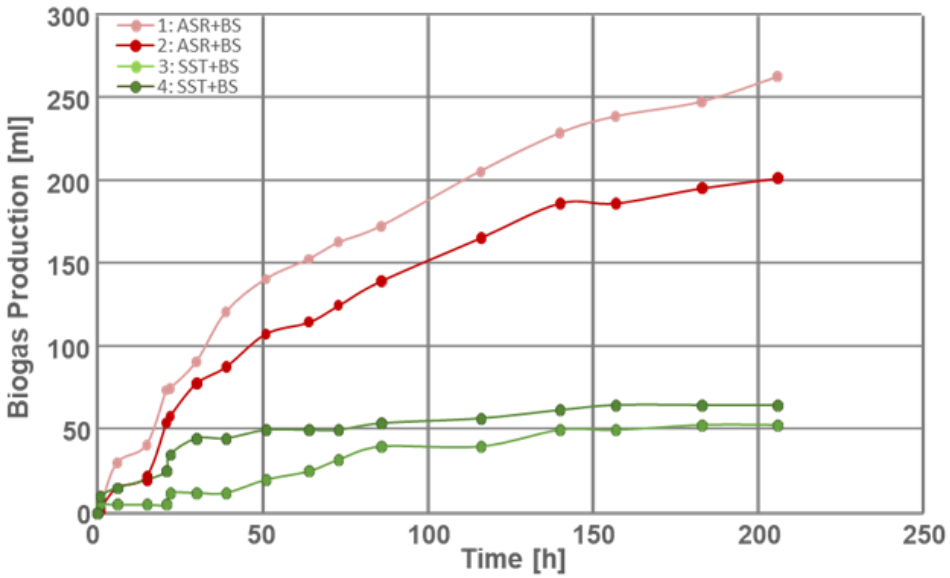

Fig. 2. Cumulative biogas production over time

3.2 Anaerobic Digestion of STT-Bacteria and Biosolids

The reference group has an average biogas production of 59ml. This value is composed of 53 ml biogas (third setup) and 65ml for the fourth one. The average production rate of the setups 3 and 4 are 0.26m l/h or 260 l/kg and 0.32 ml/h or 320 ml/kg. Likewise, the first and second setup, the production rate is not consistent and declines over time. The biogas production of all four setups is visualized in Fig. 2.

The pH decreases from 8.02 in the first place to 5.61 (setup 3) and 5.58 (setup 4) or respectively 5.60 on average.

The TSC of the fed biomass equals 2.00%. After the production period, a TSC of 1.91% (3) and 1.67% (4) are determined (Average: 1.79%).

For TAC, an increase from 26.51% (feed) to 29.91% (third setup) and 32.15% (fourth setup) can be observed. The average TAC after production time is 31.04%.

Analogous to the first two setups, RB is calculated and values of 0.40 g in the third setup.

4. CONCLUSION

Comparing the average produced biogas of the ARS-BS mixture with the SST-BS-Bacteria composition, the ARS-BS mixture produced almost four times as much biogas 60 l/kg and 240 l/kg respectively. For all performed tests, the production rate is high in the first 24 hours of fermentation and then begins to be flattering out. In this experiment, the SST bacteria used for treatment of septic systems had a low overall amount of produced biogas, yielding a lower conversion of BS of 0.71 g compared to ASR bacteria which converted 1.38 g.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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