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Tünde Alapi
Róbert Berkecz
István Ilisz

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INTENSIFICATION AND MONITORING OF ANAEROBIC FERMENTATION OF SEWAGE SLUDGE FROM THE MEAT INDUSTRY

Zsófia Gréta Sánta[1,2], Balázs Lemmer[2], Zoltán Péter Jákói[1], Sándor Beszédes[1]

[1]*Department of Biosystems Engineering, Faculty of Engineering, University of Szeged, Moszkvai krt. 9, H-6725 Szeged, Hungary*
[2]*Department of Food Engineering, Faculty of Engineering, University of Szeged, Moszkvai krt. 5-7, H-6725 Szeged, Hungary*
e-mail: zsofiasanta71@gmail.com

Abstract

My goal was to investigate the effect of different pretreatments on the quantity and methane content of biogas produced during anaerobic digestion of sewage sludge from meat processing plants. Both the accumulation of waste and the depletion of non-renewable energy resources are major problems of modern times, and the use of sewage sludge as a feedstock for biogas production may be a promising solution. Anaerobic digestion is a complex process, and the right quality of feedstock is essential for its proper completion. Although, meat industry wastewater is not ideal feedstock for biogas production, its properties can be improved by pre-treatments. In my chosen pre-treatments, we added magnetite nanoparticles to the sludge and then irradiated it with microwaves at different power levels. Monitoring the fermentation is crucial, especially in industrial practice. We monitored the progress by measuring the dielectric properties of the sludge samples.

Our results show that dielectric measurements are a promising alternative for monitoring the anaerobic fermentation because there is a clear correlation between the changes in the value of the dielectric constant and the progression of the fermentation. Our results also clearly support the positive effect of the chosen pretreatments on the amount of biogas produced during fermentation. While the amount of gas increased, the methane content of the biogas produced did not change as verified by gas analysis.

Introduction

In the past decade, rapidly increasing industrial production and the growth of the Earth's population have led to two major problems: the accumulation of waste and the depletion of non-renewable energy sources. As with other types of waste, the amount of wastewater produced by humanity has increased significantly. The extreme volumes of wastewater make it inevitable that more efficient methods of wastewater treatment and recovery must be developed.

One such modern processing method uses sewage sludge as a feedstock in biogas production. The huge advantage of this method is that not only is the biogas produced as a final product is a suitable energy source, but the process often kills pathogenic microbes that were present in the original wastewater and stabilizes the sludge. [1] So the material left over after fermentation can be usually safely used for soil improvement.

However, not all wastewater is equally suitable as feedstock for biogas production. The meat industry requires large quantities of clean water and, depending on the specific plant, the technology used and the efficiency of the water management in the plant, a large proportion of the water used is heavily contaminated. The most common and most abundant contaminants are blood, fat, bone fragments, meat scraps, hair, feathers, feces, as well as salt from marinades and chemicals used for disinfection and cleaning to meet strict hygiene requirements [2].

Therefore, the meat industry could provide a significant amount of sewage sludge as feedstock for biogas production, but this sludge in itself is more than often not optimal. In the biogas

production process, microbial bacteria and specific archaea degrade the organic matter in the feedstock under anaerobic conditions, producing an energy-rich gas mixture which has many applications.
The quality of the feedstock is essential to ensure the optimal fermentation process and the quality of the produced biogas. [3] Most of the nutrients important for microbial growth are found in flocks and consequently, has relatively low bioavailability. Furthermore, residual disinfectants and detergents can inhibit the proper activity of the gas-producing microbes. Due to these properties, it is advisable to pre-treat meat industry sludge before using them as feedstock for biogas production to improve their properties and to be able to extract biogas with higher yields and better quality.
Due to their high water-content, sewage sludges effectively absorb microwave radiation, which is absorbed and transfers its energy to the material, causing a rapid and gradual temperature rise and deterioration, which aids sludge degradation. [4] Although microwave pre-treatment cannot change the chemical composition of the sludge, it improves the bioavailability of the required nutrients by bringing the useful components into solution. However, in case of dense, thickened sludge samples the material homogeneity is usually low, and due to the microwave's selective heating ability these samples cannot be heated uniformly. To reduce temperature inhomogeneity, small-scale microwave absorbers should be mixed homogeneously with the material, such as silicon carbide, carbon nano tubes or metal nanoparticles.
The aim of my work was to investigate the effect of microwave pre-treatment of meat industry wastewater in the presence of magnetite nanoparticles on the amount and CH_4 content of biogas produced.

Experimental

The sludge used in the experiments came from a local meat processing plant. We used a Labotron 500 laboratory microwave unit operating at 2450 MHz frequency for the pre-treatments. The pre-treatments were performed at two different power levels: 250 W and 500 W. In order to keep the energy irradiated constant regardless of the power, the irradiation time was adjusting accordingly: 1.5 min at 500 W and 3 min at 250 W. For the combined pre-treatments, 15 mL of magnetite nanoparticle suspension was added to the wastewater to be fermented before microwave pre-treatment to promote uniform heating. The concentration of the suspension was 0.71 g/100 mL, while the average particle size was 110 nm. After the different treatments, inoculum sludge was added to the sludge samples to ensure the proper microbial composition. To monitor the dielectric properties of the samples, an open-ended dielectric sensor (DAK 3.5, SPEAG, Switzerland) connected to a vector network analyzer (Rhode & Schwarz, Germany) with a coaxial cable was used in the frequency range of 200-2400 MHz. During the anaerobic digestion, the amount of the produced biogas was measured with pressure sensors, and the quality (methane content) of the samples were determined with an OPTIMA7 biogas analyzer, equipped with a pair of NDIR sensors to detect CH_4 and CO_2.

Results and discussion

Our results demonstrate (Figure 1) that the chosen pretreatments had a clearly positive effect on gas production, as the control sample produced less biogas than any of the pretreated ones. The most effective pre-treatment was the one combined with magnetite particles at 250 W for 3 minutes, which produced more than three times as much gas as the control sample.
We can also see that the two pre-treatments together were more effective than either microwave treatment (at any power level tested) or nanoparticle treatment alone. This suggests that the effects of the two pre-treatments are additive, meaning that they enhance each other. One form of this is likely to be that the magnetite nanoparticles act as hotspots during heating and

successfully eliminate the temperature inhomogeneities. Regardless, the presence of metal nanoparticles stimulated gas production even without microwave heating, suggesting that the presence of iron plays a role in microbial metabolism.
Not only did the treatments have a beneficial effect on the volume of gas produced, but they also catalyzed the initiation of gas production: gas production started several days earlier in treated samples than in untreated ones.

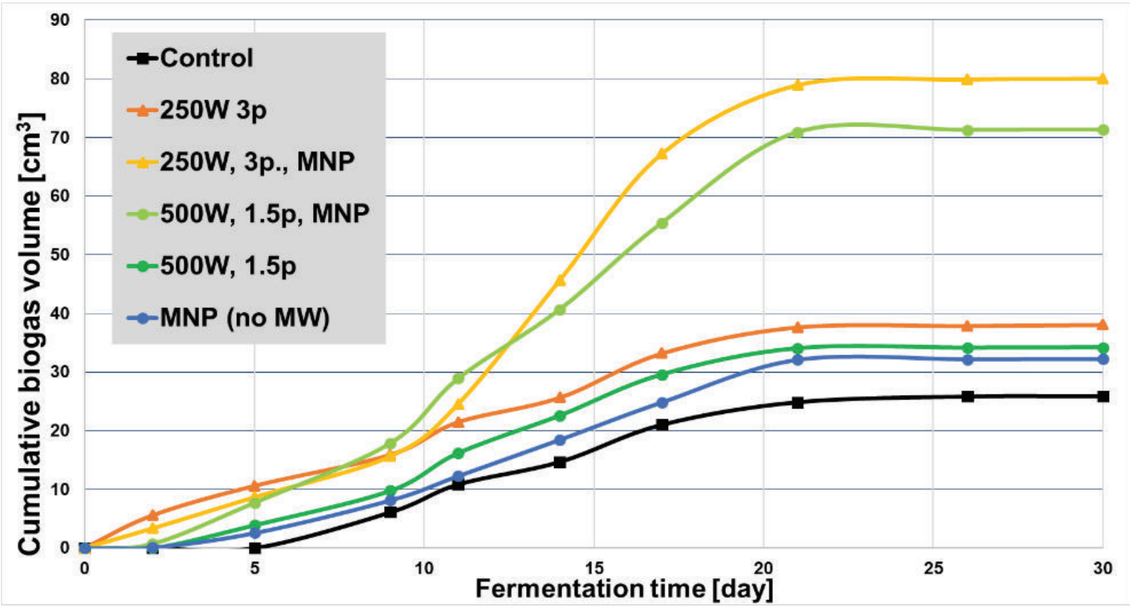

Figure 1. Changes in the total amount of biogas produced as the fermentation time progresses

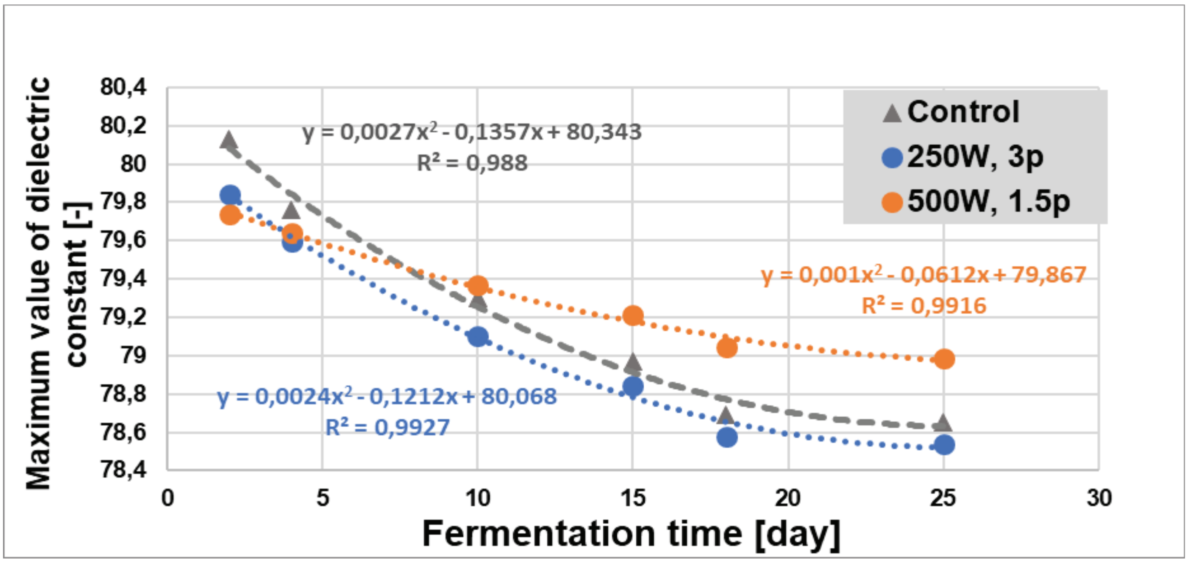

Figure 2. Changing of the maximum dielectric constant of sewage sludge during fermentation

Another focus of our research was to monitor the dielectric constant of sewage sludge samples as fermentation progressed. We measured the dielectric constant values in the frequency range 200-2400 MHz. As can be seen in Figure 2, the maximum dielectric constant of the sewage sludge decreases in a second-order trend for all samples. This suggests that the molecular

changes that take place during the different stages of the anaerobic fermentation is also reflected in the change of the system's dielectric behavior. This means that the method based on the measurement of dielectric properties can be used to monitor the fermentation process regardless of the type of pre-treatment used.
The CH_4-CO_2 ratio determined across all samples averaged 83%±2.7% in favor of methane, so there was no significant difference between the gas quality of the treated samples and the control. In other words, the applied pretreatments increased the volume of gas produced without having a negative effect on its methane content, so the amount of CH_4 produced increased notably as a result of these treatments.

Conclusion
Our results show that microwave treatment with the addition of magnetite particles increases the amount of biogas produced during anaerobic fermentation without reducing its quality. The pre-treatment at 250 W combined with magnetite nanoparticles proved to be the best. The effectiveness of the 250 W treatment is not necessarily a result of the lower power, it is possible that the longer treatment time allowed the microwave treatment to have a more uniform beneficial effects. In the future, we plan to investigate the treatment time as an influencing parameter. The earlier start of gas production is probably due to the shorter lag phase. Thus, the bacteria of the fermentation culture adapt more quickly to the new conditions and reach the state necessary for division and intensive metabolic processes. On a larger scale, such as in industrial applications, this can lead to significant cost savings. If the microbes start their metabolic processes more quickly, the required temperature and mixing levels have to be maintained for a shorter period, reducing energy and operational costs.
It can also be seen from the results that the maximum value of the dielectric constant decreases steadily as the fermentation proceeds. This decrease is present regardless of the pre-treatment and follows a second order trend. This means that we can consider the measurement of dielectric properties. a non-destructive and real-time monitoring method for sewage sludge fermentation monitoring.

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