APPLICABILITY OF DIELECTRIC MEASUREMENT IN WASTEWATER SLUDGE TREATMENTS

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Abstract

Our research work focused on the applicability of dielectric measurement methods in wastewater-sludge treatment processes. On the one hand, we wanted to investigate how the soluble chemical oxygen demand (SCOD) - a key characteristic in sewage sludge utilization - changes due to the different sludge pre-treatment processes, and whether these changes are in connection with the dielectric behaviour of the material matrix. In addition, we also investigated whether the anaerobic digestion of sewage sludge, as a bio-energy production method can be monitored by measuring certain dielectric properties. The experimental results revealed that there is a strong correlation between the change in SCOD of different types of wastewater sludge that occurs due to the applied pre-treatment methods and the dielectric constant (at f=450 MHz frequency), and we also found connection between the nascent biogas yield and the dielectric behaviour of the fermentation medium.

Introduction

Nowadays, with the growth of population, globalization and industrialization becoming more and more pronounced, it is essential to meet the ever-increasing energy demands of different industries, sectors, and services. Fossil fuels are finite and their economically viable exploitation is becoming increasingly difficult to sustain, therefor it is necessary to exploit the potential of alternative energy sources to maintain global energy stability, and to protect the environment.

Wastewater and wastewater sludge can be considered as a type of biomass, therefore their utilization for energy purposes can be considered as CO_2-neutral [1]. However, due to the complex physicochemical structure they have, a proper pre-treatment method (such as microwave or ultrasonic treatment, chemical extraction, thermal pre-treatment) is usually needed. These pre-treatment methods often aim to directly increase the soluble organic content in wastewaters, or to enhance the disintegration degree in wastewater sludge. These processes then can contribute to the more efficient utilization of wastewater and/or sludge [2].

The dielectric behavior of various (biological) materials and systems have been investigated for decades, with the aim of using the obtained results to design and optimize several biomass pre- and post-processing devices and equipment that operate at radio and microwave frequencies. Materials, when put into an electric or electromagnetic field behave differently, based upon their dielectric properties. The absolute permittivity (ε) of a material defines how well it can respond to an electromagnetic field E, and to what extent this field causes an electric displacement D in the material:

$$D = \varepsilon E \qquad (1)$$

The applied field E also plays a role in the dielectric polarization (P), which is defined by the electric susceptibility (χ):

$$P = \varepsilon_0 \cdot \chi \cdot E \quad (2)$$

ε_0 denotes the vacuum permittivity, which is $8.85 \cdot 10^{-12}$ A·s(V·m)$^{-1}$.

As opposed to vacuum, however, the polarization in normal materials does not occur in an instant, and therefore the generalized formula as a function of time should be used:

$$P(t) = \varepsilon_0 \int_{-\infty}^{t} \chi(t - t')E(t')\, dt' \rightarrow P(\omega) = \varepsilon_0 \chi(\omega) E(\omega) \quad (3)$$

From Eq. 3 it can be seen that dielectric polarization and susceptibility depends on the applied frequency, which lead to the frequency dependence of the permittivity as well. This reflects the fact that the response the material gives to the electromagnetic field can be defined basically as a phase shift (δ). Since the magnitude and phase can be determined at the same time only with complex numbers, the absolute permittivity should be addressed as a complex function of the frequency as follows:

$$\varepsilon^*(\omega) = \left|\frac{D}{E}\right| (cos\delta - i\ sin\delta) = \varepsilon'(\omega) - i\ \varepsilon"(\omega) \quad (4)$$

The real part of the complex function, ε‘ is the dielectric constant, which indicates the electric energy storing capacity of a given material. The imaginary part, ε“ is the dielectric loss factor, which (in lossy materials) covers the dielectric loss (often called as dissipation loss, which is due to the rotation and vibration of permanent or induced dipolar molecules) and the conductivity loss (which is caused by the displacement of charged particles, like free ions).

These parameters largely depend on the physicochemical properties of a given material and can drastically change when any of these properties undergo some sort of transformation. This observation supports the idea to use dielectric measurement in wastewater and sludge treatment and utilization, since during these processes, several physical and / or chemical changes happen in the material matrix. Studies have already shown that dielectric measurements can be applied in food industry to detect enzymatic reactions [3], in foresting to determine the moisture content of wood [4], and as we have already shown in one of our previous studies, to detect organic matter removal in industrial wastewater [5].

Experimental

The changes in the extent of SCOD were investigated for three different types of sludge: meat industry-originated, dairy industry-originated and concentrated municipal sludge. These sludge samples were subjected to the same pre-treatments and the SCOD was measured from the aqueous phase after each treatment, using a standard $K_2Cr_2O_7$-based COD cuvette test. The dielectric constant of the samples was then measured at a frequency of 2450 MHz using a SPEAG DAK 3.5 dielectric sensor, attached to a Rhode&Schwarz ZVL-3 vector network analyser. For the biogas fermentation process, meat industry wastewater sludge was used, and the anaerobic digestion was carried out under mesophilic conditions (38°C). The absolute pressure values in the fermenters were recorded with automatic manometric measuring heads, and the dielectric properties of the fermentation medium were measured every second day of the experiment with the aforementioned dielectric measurement kit, in the frequency range of 300-900 MHz.

Results and discussion

In the first part of the experiments, three different types of sludge were physically pre-treated with different intensities, and after each treatment the SCOD content of the samples was measured, as well as the dielectric constant at a fixed frequency of 2450 MHz. The change in SCOD was given as a proportion to TCOD (total chemical oxygen demand), SCOD/TCOD.

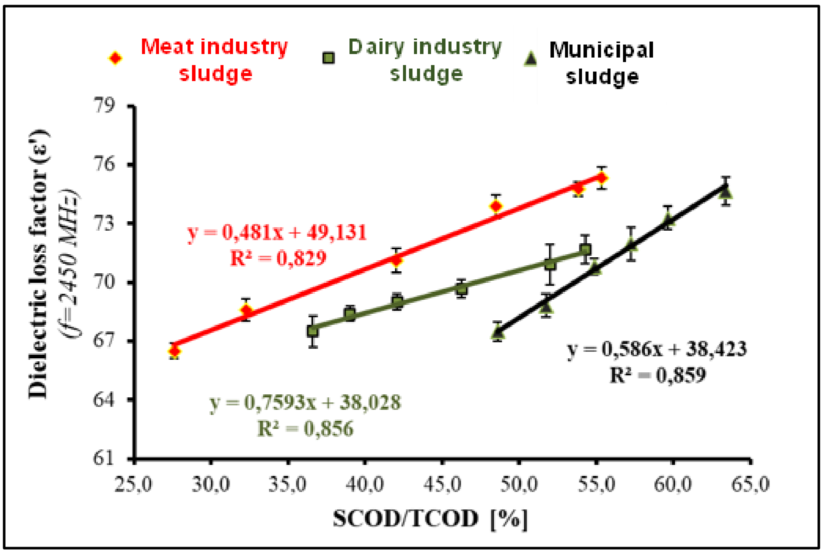

Figure 1. Correlations between SCOD/TCOD and the dielectric constant for the investigated sludge types

Based on the results, it can be concluded that the applied treatments modified the soluble COD content to different extents for different sludge types, which can be attributed to the different initial compositional proportions of the sludge samples (organic, inorganic, suspended solids, etc.) However, for all three types of sludge, there was a tendency for the SCOD values to change as a result of the treatments, with an increase in the water-soluble COD fraction, i.e. the amount of organic matter in the dissolved phase, proportional to the intensity of the treatments. The dielectric constant values determined for each sample showed a strong correlation with the water-soluble COD fraction; as the SCOD values increased, the dielectric constant values also became larger. This may be explained by the fact that the treatment, by disintegrating the sludge flocs, has resulted in the solubilization of organic molecules into the aqueous phase which are excitable at the applied microwave frequency and thus capable of absorbing more electrical energy.

In the anaerobic fermentation of meat industry sludge, the dielectric behaviour of the fermentation medium was monitored every second day of the digestion process in the frequency range of 300-900 MHz (this is the interval where the differences in the dielectric behaviour between the different materials / systems are the most observable, according to the excitation and relaxation frequencies generally typical for aqueous media). The data were analysed by comparing the maximum dielectric constant values and their corresponding frequency values for the fermentation day in the applied frequency range (Figure 2).

The results clearly show that as the anaerobic digestion process progresses, the maximum of the dielectric constant becomes lower and lower and the frequency value associated with the maximum becomes higher and higher over the frequency interval investigated. Approximating the relationship between the two variables with a second-order polynomial, the coefficient of determination is approximately 0,98, which clearly indicates a close correlation between the two values

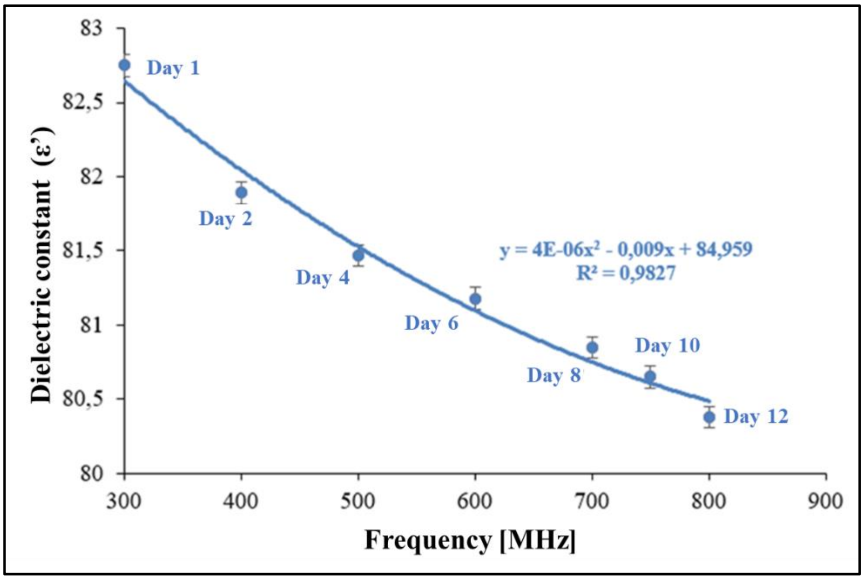

Figure 2. Frequency dependence of the maximum of the dielectric constant during anaerobic fermentation of meat industry-originated sludge

As the fermentation time progressed, the biogas yield varied according to the three distinct phases typical of anaerobic digestion (lag, log, stationery), with the stationery period occurring at the 12^{th} day. Thus, the results support that while significant biochemical changes occur in the fermentation medium, these changes are also reflected in the dielectric behaviour, i.e. the measurement method is suitable for monitoring the different phases of anaerobic digestion.

Conclusion

Our experimental results have clearly proven that physical and chemical changes that occur in the media during wastewater and sewage sludge treatment and utilization processes can be monitored by determining the appropriate dielectric parameters – a strong correlation has been found between the change in SCOD of the pre-treated different sludge samples and the dielectric constant, as well as between the fermentation stage of the anaerobic digestion of sludge and the dielectric constant.

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