

DETECTION OF EFFICIENCY OF MICROWAVE-ENHANCED SLUDGE TREATMENTS BY DIELECTRIC MEASUREMENTS

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ABSTRACT

Microwave irradiation is a promising pre-treatment method for sludge stabilisation, but there are few studies focusing its effect on organic matter solubility and biodegradability of wastewater and sludge originated from the food industry. In our research, microwave irradiation was applied standalone and in combination with alkaline treatment to enhance the solubilisation and biodegradation of organic matter content of meat industry wastewater and municipal sludge, respectively. The energy efficiency was investigated, as well. Dielectric measurement is a suitable method to detect physicochemical changes; therefore our research work covered the determination of dielectric properties of the investigated materials. Our experimental results have revealed that the lower power and energy intensity microwave-alkaline treatments were the most efficient pre-treatment process from energetically aspects to increase the organic matter solubility and biodegradability of wastewater and sludge. Furthermore, a strong linear correlation was found between the dielectric constant and the indicators of the solubility of organic matter (SCOD/TCOD) and aerobic biodegradability (BOD/COD) in both treated materials, respectively. Our results show that the dielectric measurements can be applied for detection of physicochemical changes, predict the improvement of biodegradability, and considered as a promising method to estimate the efficiency of sludge pre-treatment methods.

Keywords: wastewater, sludge, microwave, dielectric measurements, biodegradability

1. INTRODUCTION

Due to the urbanization, the increased water consumption of population and industry generate a significant amount of wastewater and sludge. Because of the high cost of operating and treatment processes, it should be taken into consideration to utilize the arising amount of sludge. Instead of deposition and incineration, the application of biological utilisation methods (e.g. composting or anaerobic digestion) are preferred to reduce the organic matter content of sludge. For economic reasons the application of different pre-treatment technologies are required to enhance the efficiency of the utilisation processes.

Microwave irradiation (MW) is proven to be a promising pre-treatment method in different food technologies and biomass utilisation based on previous studies [1, 2, 3, 4]. As a result of its unique heating mechanism provides a fast and selective heating ability [5], the applicability of microwave treatments in sludge stabilisation processes need to be investigated thoroughly. Due to its thermal effect it can enhance the disposal of sludge with the disruption of microbial cell wall. The released cytoplasm increases the soluble organic matter content of the sludge, since proteins, carbohydrates, lipids become more available for the microorganisms [6]. Alkaline dosage is a suitable chemical treatment method the increase disintegration of bacterial cell wall however, many studies pointed out that in combination with physical pre-treatments, the efficiency could be enhanced [7, 8]. The characteristics of microwave treatment of municipal sludge is vigorously investigated [5, 6, 9], but there is few studies available related to wastewater and sludge originated from the food industry.

Dielectric materials, like wastewater and sludge can absorb the microwave interval of the electromagnetic spectrum, and its extent depends on the material properties, structure, temperature and frequency. The dielectric behaviour of a material can be described with certain dielectric properties.

Complex relative permittivity (ϵ) includes the characteristics that affect the reflection of electromagnetic waves from the material interface, as well the energy loss that occurs with the absorption of the electromagnetic wave [10]. The dielectric constant (ϵ') represents the electrical energy absorption capacity

of the dielectric material, the dielectric loss factor (ϵ'') describes the dissipation ability of the dielectric material and j is the imaginary factor:

$$\epsilon = \epsilon' - j \cdot \epsilon'' \quad (1)$$

The product of free space permittivity (ϵ_0) and the relative permittivity (ϵ_r') gives the dielectric constant:

$$\epsilon' = \epsilon_0 \cdot \epsilon_r' \quad (2)$$

Measuring dielectric properties is a rapid, non-destructive way of determine structural and/or molecular changes in the raw material matrix, and such, it is a suitable method to detect the organic matter removal efficiency of wastewater treatment processes [11, 12].

The main aim of our research work was to investigate correlation between the dielectric parameters and the mentioned conventional analytical indicators (COD, BOD).

2. MATERIALS AND METHODS

In our experiments, 100-100 cm³ of meat processing wastewater and municipal sludge were used for the treatments and dielectric measurement.

The samples were pre-treated by microwave irradiation with a total energy intensity of 300, 450 and 600 J/mL at two different power levels (250 and 500 W), with the corresponding the irradiation time of 1-4 minutes. For the microwave treatments laboratory scale microwave equipment (Labotron 500) was used.

In combination with the MW treatment - as an alkaline treatment- 2 cm³ 40 m/m% NaOH solution was dosed.

To investigate the effects of each treatment on solubility the total chemical oxygen demand (TCOD) was determined. Based on previous studies focusing on the determination of soluble chemical oxygen demand (SCOD), we applied the organic matter fractionation method, i.e. sedimentation, centrifugation (RCF=6000 for 10 minutes) and filtration (0,45µm pore filter), which was followed by a colorimetric method (Hanna, COD cuvet test, after 2 hours thermodigestion at 180 °C) to determine the exact values of SCOD. The SCOD/TCOD parameter describes the ratio between the amount of organic matter in the soluble phase and the total chemical oxygen demand of the observed sample.

For the characterisation of aerobic biodegradability, biochemical oxygen demand (BOD) was measured in respirometric BOD meter, and as an indicator, the ratio of BOD and COD (BOD/COD) was used. To investigate the efficiency of biogas production lab-scale batch mesophilic anaerobic digestion tests were carried out.

For the dielectric measurements a DAK 3.5 (SPEAG) open-ended coaxial dielectric probe was used, connected to a ZVL-3 vector network analyser (Rohde&Schwarz). The dielectric properties – the dielectric constant (ϵ') and the dielectric loss factor (ϵ'') - were measured in the frequency range of 200-2400 MHz, at the temperature of 28 °C.

3. RESULTS AND DISCUSSION

In our research work, we applied different power and energy intensity microwave treatments standalone and in combination with alkaline dosage in order to enhance the solubility and biodegradability of meat processing wastewater and municipal sludge. Our results show microwave-alkaline combined pre-treatments increased the most the indicators of organic matter solubility (SCOD/TCOD), since it affects the SCOD/TCOD parameter in a way which indicates that the solubility of the organic compounds of the treated material is enhanced in the soluble phase. When combined pre-treatment was applied the indicator of aerobic biodegradability (BOD/SCOD) also shows a larger growing tendency compared to the raw control and the standalone MW treatments, since the increased solubility causes better availability of the

organic matter for the microorganisms in the soluble phase. The MW-alkaline treatments enhanced the biogas yield of anaerobic digestion tests, as well. Furthermore, from energetically aspects those processes were the most efficient, when the NaOH treatment was intensified with MW irradiation, especially on lower (2.5 W/mL) power levels.

In our study, besides the investigation of energy efficiency of each treatment, we also focused on the determination of correlation between dielectric parameters, solubility and biodegradability indicators.

After the pre-treatments, each sample was cooled to the temperature of 28°C to carry out the dielectric measurements. The results of dielectric measurement show that the ratio of dielectric constant (300MHz/2400MHz) has a linear correlation with the SCOD/TCOD in both treated materials, respectively:

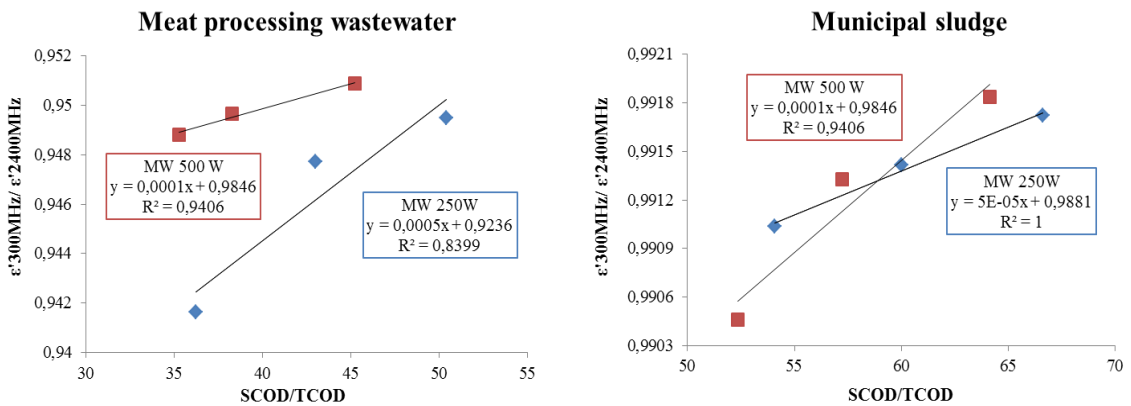


Figure 1. The correlation between SCOD/TCOD and ratio of dielectric constant (300MHz/2400MHz)

Figure 1. shows that the applied power intensity and the type of treated material affect the regression equations, but the presented correlation is independent from these factors. The higher organic matter solubility can be traced back to the degradation effect of the MW on the solid particles and the macromolecules of the sludge, causing deflocculation [12].

As the indicator of aerobic biodegradation, the ratio of BOD and COD were determined (Fig.2).

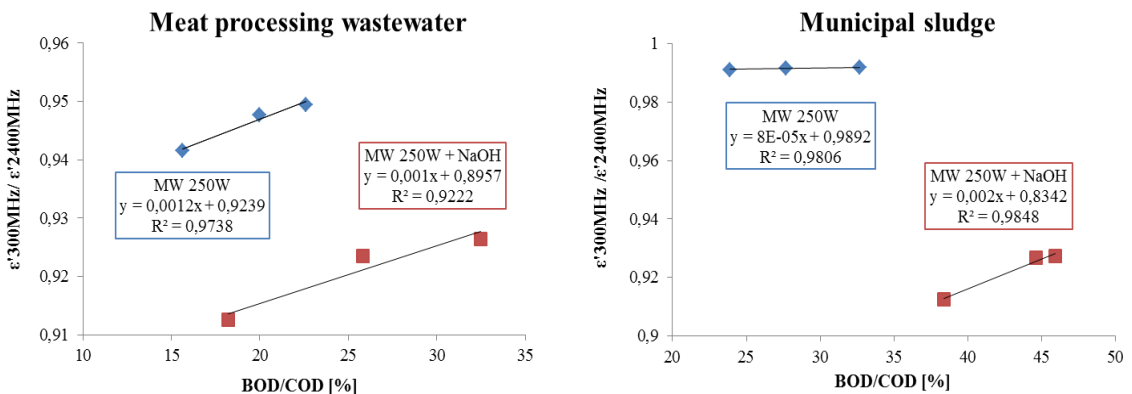


Figure 2. The correlation between BOD/COD and ratio of dielectric constant (300MHz/2400MHz)

Similarly to the solubility (Fig.1), the BOD/COD ratio also shows a strong linear correlation with the determined ratio of dielectric constant ($\varepsilon'_{300\text{MHz}} / \varepsilon'_{2400\text{MHz}}$) in meat processing wastewater and municipal sludge, respectively. This result verifies the connection with the increased organic matter solubility.

Based on the results of our research, dielectric measurement is an applicable method to investigate the changes of the organic matter content in food industry wastewater and municipal sludge. In order to get more accurate and detailed information about the dielectric behaviour of these materials, further investigation is needed and the range of measuring frequency should be extended. The determination of dielectric properties - in the presence of appropriate correlations – could be a faster, more precise, chemical free and non-destructive method for the characterisation treated sample. Thereby, dielectric measurement is concluded suitable for the estimation of the expected efficiency.

4. CONCLUSIONS

In this study we compared the efficiencies of different energy and power intensity standalone and alkaline-combined MW treatments on the solubility of organic matter in meat industry wastewater and municipal sludge samples. Based on our results, microwave irradiation, especially in combination with alkaline-dosage is proved to be an applicable wastewater and sludge pre-treatment method. The lower power level MW- alkaline treatments intensified the solubility and biodegradation of organic matter content, in aerobic (BOD/COD) and anaerobic (increase of biogas yield) ways, as well.

In order to gain a more detailed understanding of how microwave irradiation affects the other raw material matrix of different sludge samples originated from the food industry, further researches are recommended. Our study also focused on to investigate the correlation between the dielectric constant (ε'), solubility and aerobic biodegradability indicators (SCOD/TCOD, BOD/COD). With the application of dielectric measurement the change in the solubility and biodegradability of organic matter can be detected, since these parameters and the change of dielectric constant and shows a linear correlation between each other. The results show that dielectric measurement is proved to be a promising detection method to estimate the efficiency of various sludge pre-treatments.

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