ANAEROBIC CO-DIGESTION OF SEWAGE SLUDGE AND HERBAL WASTE IN THE PRESENCE OF A ZEOLITE

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In the age of climate and energy crises, the development of the global economy in various industries faces an unprecedented challenge related to reducing the dependence on fossil fuels. The problem of alternative energy sources and energy security is becoming a global issue. In response to these challenges, the European Union is focusing on the transition to advanced biofuels produced from sustainable raw materials. An innovative approach based on lignocellulosic waste biomass as a renewable energy source may be a promising solution with high energy potential (Abraham et al., 2020). The sources of lignocellulosic biomass are agricultural waste, including herbal waste, forestry waste, as well as the organic fraction of municipal and industrial waste (wood, paper) (Roy et al., 2021).

Currently, the preparations used in natural medicine, cosmetics, and healthy foods are attracting increasing attention and interest from consumers. As a result, there is a growing demand for herbal raw materials, which leads to a gradual increase in the amount of herbal waste generated. Herbal waste can be used and processed in briquetting or pelletizing processes, and the products of these processes can be used as fuel (combustion) or animal feed (Obidziński et al., 2017). However, there are no reports in the literature on the possibility of using herbal waste in biological processing. Due to its physicochemical composition, significant content of organic matter, micro- and macroelements, as well as nutrients, lignocellulosic biomass waste of herbal origin can be a beneficial substrate or co-substrate for the methane fermentation process. According to the studies conducted by many researchers, lignocellulosic biomass has high methane potential, but its phenol content and complex structure may negatively affect the biogas production efficiency (Paudel et al., 2017; Kumari and Singh, 2018). This paper evaluates the possibility of using natural zeolites as substances that absorb phenolic compounds from herbal waste in the process of mesophilic anaerobic co-digestion (AcD) of herbal waste (HW) with sewage sludge (SS).

The main substrate, SS (mixture of thickened primary and excess sludge) was obtained from mechanical–biological WWTP located in Lublin (Poland). Under laboratory conditions, both types of sludge were mixed at the volumetric ratio of 60:40 (primary:excess). The inoculum for AcD was obtained from the same facility; it was taken from the outlet of mesophilic anaerobic digester. HW were chosen as co-substrates for SS and was taken from a local herbal industry. The applied zeolite, was a natural resource-obtained zeolitic tuff from a quarry near Nižný Hrabovec located in Slovakia. The impact of zeolite application on the AcD of SS and HW was investigated in a batch system experiment. The BioReactor Simulator, supplied by BPC Instruments AB (BPC Instruments AB, Lund, Sweden), was used as a laboratory installation. This installation comprised two units, with the first unit containing six anaerobic reactors, each fitted with a mixing system, and submerged in a water bath to maintain a consistent temperature of 35°C; the second one was applied to constantly monitor the volume of the generated biogas.

The working volume of each batch reactor was 2000 mL; they contained 1400 mL of inoculum and 400 mL of SS. In this study, three experimental series were planned, according to the following assumptions: R1—control series, mono-digestion of SS; R2—AcD of SS and HW; R3—AcD of SS and HW in the presence of a zeolite. In series R2 and R3 the doses of HW were 3.0 g. The amount of the applied zeolites in R3 was 2.0 g. The fermentation time was 21 days. From the technological point of view of the lignocellulosic biomass fermentation process, the possible inhibition by phenols is an important factor. Phenols have a toxic effect on

microorganisms responsible for individual stages of fermentation, especially methanogens. Even at low concentrations, they can inhibit enzymatic activity and reduce biogas production, and they also affect the structure of the microbiome (He et al., 2022). Furthermore, they can lead to the accumulation of intermediate products (e.g. volatile fatty acids) as they inhibit the processes of hydrolysis, acidogenesis and acetogenesis (Prem et al., 2023). The phenol content in the feedstock was 64.3 mg dm^{-3}, 69.2 mg dm^{-3} and 71.1 mg dm^{-3} for R1, R2 and R3, respectively. The addition of herbal waste increased their concentration in the mixtures feeding the reactor. In the case of digest, an increase in their concentration compared to supply was observed; the largest increase (49%) was recorded in series R2, where SS and HW were fermented without the zeolite addition. When the zeolite was used (R3), the increase in phenol concentration was 31%. The lowest phenol concentration in the digest as well as the lowest increase during the process were observed in the sewage sludge mono-fermentation series (R1). This was also reflected in biogas production. The highest biogas production of 190 ml gVS^{-1} was reported in the R3 series, while the lowest in R1 (167 ml gVS^{-1}).

In summary, the addition of a natural zeolite to the co-fermentation process of sewage sludge and herbal waste may have a beneficial effect on the possible process inhibition by phenols introduced into the system together with lignocellulosic waste biomass. The studies also suggest that the use of a zeolite has a beneficial effect on the amount of biogas produced.

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