

# Wastewater Treatment and Biogas Production: Innovative Technologies, Research and Development Directions

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## 1. Background and Purpose

The development of wastewater treatment methods and the processing of sewage sludge is associated with the search for new, efficient and technologically justified solutions, the use of which will be an alternative to the systems used thus far. The main goal is not only to obtain the highest possible effects of neutralization and pollutant removal but also to achieve the assumed technological effects with a significant reduction in investment and operating costs. The adoption of these criteria has led to significant interest in anaerobic technologies, a dynamic increase in the number of available solutions and the implementation of such systems on a technical scale. A further dynamic global increase in the interest and importance of anaerobic technologies used in wastewater management is forecasted.

Anaerobic bioreactors offer a wide range of applications in wastewater treatment systems and sludge management in the municipal and industrial sectors. Methane fermentation systems allow for efficient biodegradation of organic compounds with relatively low investment and operating costs. The advantage is the limited amount of anaerobic excess sludge production and the low space requirement for the installations and accompanying facilities. The strong point of digestion technologies is the possibility of producing and capturing biogas with high methane content. It has been proven that the use of anaerobic methods is particularly justified in the case of wastewater and sewage sludge with a high organic pollutant load. However, anaerobic technologies also have many limitations, such as difficulties removing biogenic compounds and the need to provide a relatively high and stable temperature or methods of preliminary substrate pre-treatment. Therefore, there is a justified need to search for universal methods that will be competitive in terms of investment and technology to the currently existing solutions.

The aim of the Special Issue, entitled “Wastewater Treatment and Biogas Production”, was to indicate the strengths and weaknesses of digestion systems, characterize technological parameters influencing the course of anaerobic wastewater treatment and sewage sludge neutralization, present design solutions for bioreactors together with the assessment of their technological effectiveness and indicate potential directions of anaerobic methods development.

## 2. Overview of Undertaken and Research Issues

The issues of the submitted work can be divided into separate research areas concerning important topics in the field of anaerobic technologies used in wastewater treatment systems and sewage sludge management. The published works covered a wide research area related to the development of this type of solution, from innovative reactor designs through the technological issues of wastewater fermentation and modelling of the wastewater treatment to sludge pre-treatment and the impact of these processes on the final technological efficiency.



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### 2.1. Wastewater Treatment Technologies

Mpfou et al. [1], in their research, focused on the assessment of anaerobic co-digestion of tannery and slaughterhouse wastewater for reducing solids and recovering resources. They focused their attention on the impact of a high sulphate concentration in the wastewater and the inoculum-to-substrate ratio (ISR) on the efficiency of pollutant removal and production efficiency, as well as the qualitative composition of biogas. It has been proven that methanogenic activity and  $\text{CH}_4$  yields were high when reactors were operated  $\text{ISR} \geq 3$  and/or lower  $\text{SO}_4^{2-} \leq 710 \text{ mg/L}$ , while high  $\text{SO}_4^{2-} \geq 1960 \text{ mg/L}$  and  $\text{ISR} < 3.0$  caused almost complete inhibition regardless of corresponding ISR and  $\text{SO}_4^{2-}$ . The optimization carried out has shown that the theoretical optimum operating conditions ( $922 \text{ mg/L SO}_4^{2-}$ ,  $\text{ISR} = 3.72$ ) are expected to generate  $361 \text{ mL biogas/gVS}$ ,  $235 \text{ mL CH}_4/\text{gVS}$ , with reduction efficiencies of 27.5% VS, 27.4% TS, 75.1% TOC, 75.6%  $\text{SO}_4^{2-}$ , and 41.1% COD [1].

Dębowski and Zielinski [2] conducted research to determine the impact of fluidized active filling on the effectiveness of the anaerobic treatment of sugar-industry effluent and the production efficiency and qualitative composition of the biogas produced. The research was carried out on a fractional-technical scale. The fluidized active filling (FAF) method presented in this paper is an innovative solution not previously used to treat sugar-industry effluent. Sewage treatment processes may be further supported by enriching filling components with metal additives and magnetic fluid activators, which has been shown, for example, to reduce the surface tension of the effluent, promote biogas removal and facilitate the hydrogen sulfide fixation by iron ions [2]. Within the studied OLR range of  $4.0\text{--}6.0 \text{ kg COD/m}^3\cdot\text{d}$ , the COD removal rate was higher than 74%, leading to a concentration of  $879 \pm 235$  to  $1141 \pm 206 \text{ mg O}_2/\text{dm}^3$  in the outflow. At these experimental stages, the methane content in the biogas was around 70%. Increasing OLR to  $6.0 \text{ kg COD/m}^3\cdot\text{d}$  led to a significant reduction in the observed results of methane digestion of the sugar-industry effluent. Decreased effluent treatment and methane fermentation efficiencies were correlated with an observed pH decrease to  $6.75 \pm 0.18$  and the FOS/TAC ratio increase to  $0.44 \pm 0.2$  [2].

Żyłka et al. [3] presented the issue related to energy consumption in the oxygen system of dairy wastewater treatment. Modeling and evaluating the energy efficiency of classical wastewater treatment systems based on the activated sludge method is an important issue. Based on this type of analysis, decisions are made related to the modernization of wastewater treatment plants and the change in technology to more efficient anaerobic systems. The research aimed to elaborate on models for the estimation of energy consumption during dairy WWTP operation. These models can be used for optimizing electric energy consumption. The research was conducted in a dairy WWTP, operating with dissolved air flotation (DAF) and an activated sludge system. The obtained models provided accurate predictions of DAF, biological treatment, and the overall WWTP energy consumption using chemical oxygen demand (COD), sewage flow, and air temperature. Using the energy consumption of the biological treatment as an independent variable, as well as air temperature, it is possible to estimate the variability of the total electric energy consumption [3].

### 2.2. Sewage Sludge Managements Technologies

Zawieja and Warwag [4] aimed to determine the effect of chemical disintegration with peracetic acid on biogas production efficiency using methane fermentation of pretreated sludge. The disintegration of excess sludge before methane fermentation plays an important role by supporting the biochemical decomposition of sludge under anaerobic conditions. A novelty aspect of the research is the use of a highly effective method of oxidation of excess sludge with peracetic acid (PAA), taking into account the selection of the most favorable treatment conditions to increase the effectiveness of methane fermentation [4]. Sludge pre-treatment with peracetic acid (PAA) increased the soluble chemical oxygen demand and the correlated increase in the concentration of volatile fatty acids, as determined in the filtrate fluid of the pre-treated sludge. During methane fermentation of sludge subjected to chemical disintegration with a reactant dose of  $3.0 \text{ mL of STERIDIAL W-10/L}$ , the highest

value of daily biogas production (0.28 L) was observed on the tenth day of the process. The total biogas production was 3.53 L, which translated into a specific biogas production of 0.52 L/g VSS [4].

Kazimierowicz et al. [5] also assessed the effect of pre-treatment on the effectiveness of sewage sludge digestion. The aim of the study was to determine the low-temperature conditioning of excess dairy sewage sludge using solidified carbon dioxide on the efficiency of methane fermentation. Few pieces of worldwide literature have been devoted to the feasibility of the low-temperature conditioning of excess dairy sewage sludge (DSS) using solidified carbon dioxide (LTC-SCDO). The cause of microbial death during freezing, including SCDO freezing, is an increase in the volume of water freezing in the cytoplasm, mechanical damage to the wall and cell membrane, osmotic shock and destruction of cellular organelles. Considering DSS characteristics and structure, as well as the available literature data, the use of the LTC-SCDO technology can offer both a technologically and energetically viable alternative to other methods [5]. The highest COD values, ranging from  $490.6 \pm 12.9$  to  $510.5 \pm 28.5$  mg·dm<sup>-3</sup>, were determined at a ratio of solidified carbon dioxide to excess dairy sewage sludge ranging from 0.3 to 0.5. The LTC-SCDO caused the ammonia nitrogen and phosphates concentration to increase in the dissolved phase. The highest unitary amount of biogas, reaching  $630.2 \pm 45.5$  cm<sup>3</sup>·g o.d.m.<sup>-1</sup>, was produced in the variant with the volumetric ratio of solidified carbon dioxide to excess dairy sewage sludge of 0.3. The methane content of the biogas produced was at  $68.7 \pm 1.5\%$  [5].

Zieliński et al. [6] determined the effect of a 17.6 mT static magnetic field (SMF) on the efficiency of anaerobic digestion (AD) of municipal sewage sludge (MSS). Only a few reports can be found on the use of the static magnetic field (SMF) to improve the anaerobic digestion of MSS. In the studies conducted so far, the magnetic field has usually been applied to separate solids, such as, e.g., activated sludge, from the effluent. As demonstrated in other studies, the SMF also influences the growth and metabolism of bacteria. The SMF had a significant impact on methane production efficiency, the fermentation rate level, removal rate and the structure of the anaerobic bacteria consortium, but it did not affect cumulative biogas production [6]. The highest CH<sub>4</sub> yield ( $431 \pm 22$  dm<sup>3</sup>CH<sub>4</sub>/kgVS) and the highest methane content in the biogas ( $66.1 \pm 1.9\%$ ) were found in the variant in which the SMF exposure time was 144 min/day. A longer anaerobic sludge retention time in the SMF area significantly decreased AD efficiency and caused a significant reduction in the number of methanogens in the anaerobic bacteria community [6].

Kowalczyk i Kamizela [7] discussed the possibilities of using an artificial neural network to predict the dewatering efficiency of physically conditioned sludge. One of the key benefits of neural networks as forecasting tools is the fact that through the learning process, the network can acquire the ability to predict the output signals solely on the basis of observing the so-called learning series (i.e., a specified number of sequences of input and output signals serving as historical empirical data). This study aimed to investigate the usefulness of artificial neural networks in the technology of conditioning and dewatering of sewage sludge [7]. The authors proved that the effective conditioning and dewatering of the sludge were influenced by the dose of the skeleton builders, the sonication parameters and the value of the relative centrifugal force. The best results were obtained using: a dose of 3% of the dry mass of the sludge, 120 s sonication at an amplitude of 120 µm and an overload of 7550 g. This conditioning method reduced the hydration of the centrifugal dewatered sludge from about 98 to 83.2%, with a separation factor of 90% [7].

### 3. Summary

Technologies for producing biogas from sewage and sewage sludge are gaining more and more popularity among operators of municipal management systems. Despite the fact that many solutions are successfully used on a technical scale, universal and effective methods of improving the economic and technological efficiency of such processes are still being sought. The research works presented by the authors fit into this current research direction and are very important from the application point of view. The research directions

undertaken by the authors will be of great interest to the scientific community, as evidenced by the number of citations to date. Published works have been cited 26 times so far. Taking into account the assumptions of the circular economy, the preferred direction of material and energy recycling and the need to reduce CO<sub>2</sub> emissions, which is directly related to the search for energy-saving technologies in the municipal sector, it should be recognized that intensifying anaerobic pollution degradation processes' efficiency will be an important research direction.

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