# Design and study of the operation of a green waste composter with energy cogeneration

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***Abstract:*** *Nowadays, renewable bioenergy is considered as one of the ways to provide energy at the expense of fossil fuels. The possibility of obtaining energy from organic materials through bio-electrochemical systems attracts considerable interest. Green waste is organic plant-based materials generated from grass clippings, broken branches, fallen trees and others, the utilization of which is currently not very effective. In the present study, we constructed a composter based on bio-electrochemical systems for the utilization of green waste with cogeneration of energy. The composter showed good performance in terms of both the decomposition of organics and the generated energy.*
***Keywords****: GREEN WASTE, GREEN ENERGY, WASTE MANAGEMENT, BIO-ELECTROCHEMICAL SYSTEMS*

## *1. Introduction*

In the current era of increasing energy demands and the urgent need to mitigate climate change, researchers and scientists are constantly searching for innovative and sustainable solutions to meet energy needs. Increasing industrialization and a growing population require a huge amount of electricity. Bioenergy from waste biomass is seeking a lot of attention nowadays due to the rapid depletion of fossil fuels. [1] One such solution for electricity generation is the development and use of microbial fuel cells using the conversion of waste biomass. Renewable energy, such as solar energy, wind energy, hydropower, and geothermal energy, are considered as sources of sustainable energy. They are clean energy compared to coal and nuclear energy, as coal power and nuclear power plants can pollute the air and release radioactive waste, potentially harmful to human health and the ecological environment. [2] Bioenergy from the organic fraction of municipal solid waste, food waste, agricultural organic waste, forestry wood waste, and others has the potential to produce electricity, methane, and hydrogen through combustion, microbial fuel cells, anaerobic digestion, microbial electrolysis cells, and fermentation. [3] Microbial fuel cells are believed to have the potential for environmental remediation and electricity generation from organic pollutants, biomass, and organic waste through microbial biodegradation.

The current linear economy assumes abundant, readily available and cost-effective natural resources. However, this assumption is unsustainable. In contrast, the circular economy reduces waste and improves resource efficiency, making it a more sustainable alternative to the dominant linear model. Biomass energy generated from agricultural residues, forest waste and municipal waste provides a renewable substitute for fossil fuels. This reduces greenhouse gas emissions and improves energy security. Proper waste management, including waste reduction, recycling and innovative waste-to-energy technologies, reduces the burden on landfills and incineration, and creates renewable energy from materials that would otherwise go to waste. [18]

Waste and by-products of plant origin, such as bark, leaves, grass, seeds and others, can be utilized by extracting valuable nutrients and converting them into soil fertilizers. Reducing plant waste not only benefits the environment, but also contributes to various social programs by reducing greenhouse gas emissions, improving ecosystem services and implementing sustainable resource management policies. [5] Using industrial plant waste for higher value-added purposes can save significant amounts of $CO_2$. Anaerobic digestion has been identified as the preferred option compared to incineration, offering the highest environmental benefit. Recycling and reuse of agricultural waste are promising options for sustainable waste management and energy production. Choosing the right approach to utilize plant waste is crucial for cost-effective resource management and conservation. The economic impact of plant waste is closely related to its valuation, the processes used, and the economic benefits that depend on the final product. [1]

The European Union Green Deal is a comprehensive set of policy initiatives aimed at improving the EU economy for sustainable development and reducing greenhouse gas emissions to net zero by 2050. It supports a circular economy model that aims to minimize waste, reusing materials and recycling products to reduce environmental impact. In the long term, plant waste and plant-based by-products are very important because they are valuable resources that can be reused to reduce environmental impact and improve resource efficiency. [6] Furthermore, converting these waste streams into energy supports efforts to combat climate change, reduce waste and optimize resource use.

Agricultural biowaste is obtained through various biological sources and industrial processing, which is a typical renewable energy source with abundant nutrients and easily biodegradable organic matter. These waste materials are capable of being degraded under aerobic and anaerobic conditions. The projected global population, urbanization, economic development and changing production and consumption behavior lead to abundant production of biowaste. These biowaste mainly contain starch, cellulose, proteins, hemicellulose and lipids, which can serve as low-cost raw materials for the development of new value-added products, as well as the production of bioenergy through bio-electrochemical systems. [7]

Biomass is an available and carbon-neutral energy source that can contribute to the efforts to meet the rapidly growing need for cost-effective energy materials for bioelectrochemical systems. However, the challenges and costs associated with finding specialized biomass could hinder its widespread application in bioelectrochemical systems. Waste-derived biomass could be a promising alternative to specialized biomass for energy production through bioelectrochemical systems. Therefore, the use of biomass wastes (e.g., grass, agricultural and forestry wastes, and others) is an attractive strategy for the commercialization of bioelectrochemical systems. Furthermore, the application of waste biomass resources as energy sources in bioelectrochemical systems can significantly reduce their environmental and health risks. [8]

A group of microorganisms use the organic matter for their growth and start releasing protons and electrons. *Clostridium acetobutylicum*, *Clostridium thermohydrosulfuricum*, *Saccharomyces cerevisae*, *Lactobacillus* and others are very well-known examples of bacteria used to produce bioenergy in the form of electricity. Exoelectrogenic microorganisms, usually belonging to the *Geobacter* and *Shewanella genera*, can transfer electrons from organic materials to the anode surface, which leads to microbial metabolism and energy production. [9] Composting is a biological fermentation technology that converts agricultural and forestry waste into valuable resources. In the composting process, organic matter undergoes mineralization and humification under conditions controlled by microorganisms. [10] However, the optimal conditions under which microbial fuel cells can generate energy during the composting process have not been sufficiently studied. Conventional composting under aerobic conditions requires more energy for mixing and aeration, which can lead to huge amounts of leachate. Anaerobic composting, also known as anaerobic digestion, can be an alternative solution for converting solid waste into reusable energy and biofuel. [11]

Microbial fuel cells are typically operated with a liquid organic phase because the ion transfer process is efficient in a liquid medium. However, some researchers have investigated the potential of operating microbial fuel cells with a solid organic phase (especially for solid waste treatment). This is promising if several important factors are optimized, such as the type and amount of substrate, the microbial community, the system configuration, and the type and number of electrodes, which increases the amount of electricity generated. [12] The critical factor that affects the performance of a microbial fuel cell is the efficiency of electron and proton transfer through the solid medium. However, this limitation can be overcome by improvements in the electrode system and regular mixing of the substrate. [13] Integrating microbial fuel cells with other conventional solid waste treatment methods can be used to produce sustainable green energy. Although microbial fuel cells produce relatively small amounts of energy compared to other waste-to-energy methods, bioelectrochemical systems still hold promise for achieving zero-emission treatment. [14]

Recently, it has been found that microbial fuel cells can be a technology for alternative treatment and generation of electricity from waste without intermediate treatment steps, since anaerobic digestion uses electrogenic microorganisms. The bioelectricity of microbial fuel cells depends on the electron transfer process and the efficiency of biodegradation of solid waste. [15] Many researchers use the term solid-phase microbial fuel cells for MFCs that convert solid waste into electricity. However, some researchers use the term compost microbial fuel cells. [16] Solid-phase microbial fuel cells (SMFCs) are one of the innovations in MFC technologies that can be applied to solid waste. They have been found to accelerate the anaerobic digestion process of waste, directly generate electricity, and produce mature compost from organic compounds. Solid-phase microbial fuel cells are cost-effective because they require inexpensive materials for their construction and operation. [17] Furthermore, their ability to generate electricity makes them a direct alternative source of renewable energy, which has attracted considerable attention from researchers. Also, solid-phase microbial fuel cells are an alternative method to overcome the problem of solid waste treatment, as it uses them as a substrate to provide an environmentally friendly and sustainable source of electricity. [18] Therefore, solid-phase microbial fuel cells are considered capable of addressing multi-sectoral problems, as they can be integrated with other waste treatment methods, such as aerobic composting or anaerobic digestion.

This study focuses on the development of a prototype composter with cogeneration of energy by integrating microbial fuel cells with a conventional plant biomass treatment method. The study also aims to establish the efficiency and performance of the constructed facility.

## 2. Materials and methods

### *Plant biomass*

For the purpose of the study, plant biomass was taken from campus of University of mining and geology “St. Ivan Rilski”, Sofia, Bulgaria (42.6604710456078, 23.35296900986125). The plant biomass consists mowed grass with a length of 10 - 15 centimeters. In plant biomass, ancestral species are *Cynodon dactylon*, *Capsella* and *Taraxacum*.

### *Construction of SMFC biosensor*

The composter is a plastic container with a volume of 360 $cm^3$. The composter consists of 24 PVC pipes arranged vertically. Each PVC pipe has a diameter of 110 mm and a height of 900 mm. The bottom of the pipes is closed with PVC plugs. At the bottom of the pipes are located stainless steel AISI 304 electrodes with an area of 414.48 $cm^2$ acting as an anode. At the top of the pipes is a second stainless steel AISI 304 electrode with an area of 414.48 $cm^2$ acting as a cathode. Copper wires were used as conductors in the electrical circuit. Each of the 24 tubes represents a solid-phase microbial fuel cell (SMFC). Then the plant biomass was placed in the tubes and filled with water. The approximate volume of plant biomass in each tube is 7.5 $dm^3$. The physicochemical characteristics of water was pH 7.12, Eh 352 mV and EC 73 µS $cm^{-1}$ measured by Vernier LabQuest Mini. On Figure 1 is shown a scheme of single segment (PVC pipe) of the composter.

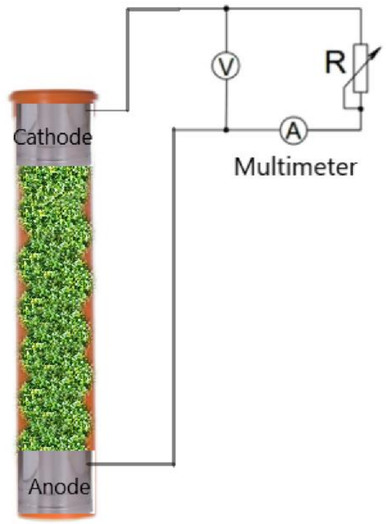


***Fig. 1*** *The schematic diagram of single segment (SMFC) of the composter*

The individual segments (SMFCs) (fig. 2) were stacked in the plastic container and after the segments reached a base voltage, the electrical parameters of the composter were measured. The electrical parameters were measured with the segments connected in series and in parallel. Then the segments were connected in series 12x12 and both pairs connected in parallel, and the electrical parameters were measured again.

***Fig. 2*** *Photo of single segment of the composter*

### *Electrochemical analysis*

To determine the operation and effectiveness of the composter polarization and power curves were obtained by varying external resistances sequentially from 10, 8, 6, 4, 2, 1.5, 1.3, 1, 0.7, 0.5, 0.3 to 0.1 KΩ using MCP lab electronics BXR-04 ResistorBox. The voltage dynamic were measured and recorded in real time with Vernier LabQuest Mini and Logger Lite software.

## *3. Results and discussion*

After filling all segments of the composter with plant biomass, the dynamics of the open-circuit voltage of the individual segments was monitored. Figure 3 presents the averaged voltage data of the individual segments.

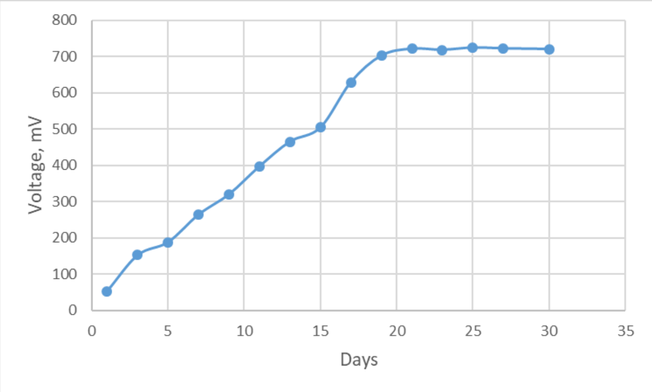


***Fig. 3*** *Average open circuit voltage of individual segments of the composter*

The graph shows that after filling the segments with plant biomass, a slow, smooth increase in the open circuit voltage begins. The voltage increases until the 19th day after filling with plant biomass, after which the segments begin to maintain an average base voltage of 725 mV.

The following experiments aimed to determine the electrical parameters of the composter with different connection schemes for the individual segments. They were carried out after the voltage on all segments had stabilized.

Figure 4 presents the electrical parameters of the composter when the individual segments are connected in series.

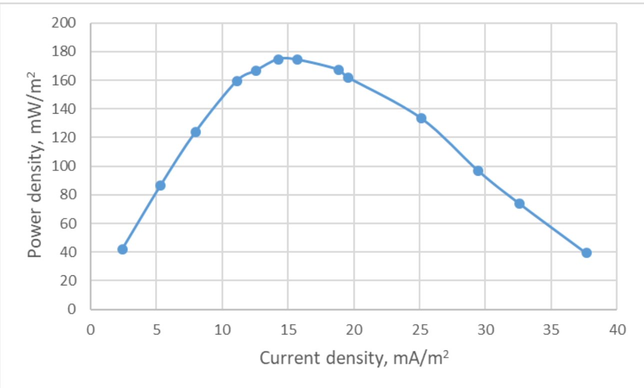


***Fig. 4*** *Power density dynamics when connecting segments (SMFCs) in series*

The graph shows that when connecting the individual segments of the composter in series, a maximum power density of 178 mW/m$^2$ is achieved at a current density of 14.7 mA/m$^2$. The maximum power density was achieved with an applied resistance of 1.5KΩ. When connecting the composter segments in series, a maximum open circuit voltage of 17.428 V was reached.

The next measurement aimed to determine the electrical parameters of the composter when the individual segments were connected in parallel. Figure 5 presents the results of this measurement.

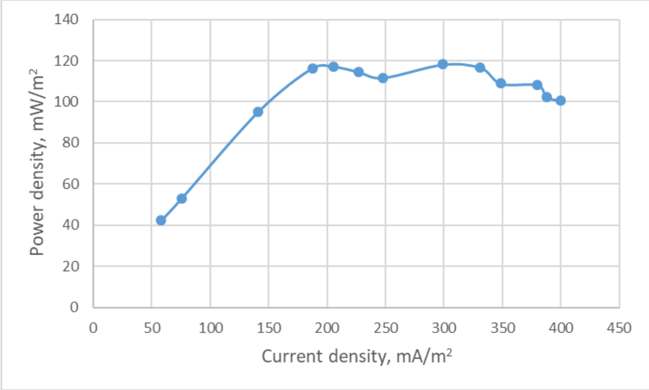


***Fig. 5*** *Power density dynamics when connecting segments (SMFCs) in parallel*

This connection achieved a lower power density than the series connection, but a significantly higher current density. The maximum power density of 119.56 mW/m$^2$ was measured at a current density of 299.82 mA/m$^2$ and an applied resistance of 1.1 kΩ.

The last experiment aimed to determine the electrical parameters of the composter when connecting 12x12 segments in series and connecting the two pairs in parallel. The results obtained are shown in figure 6.

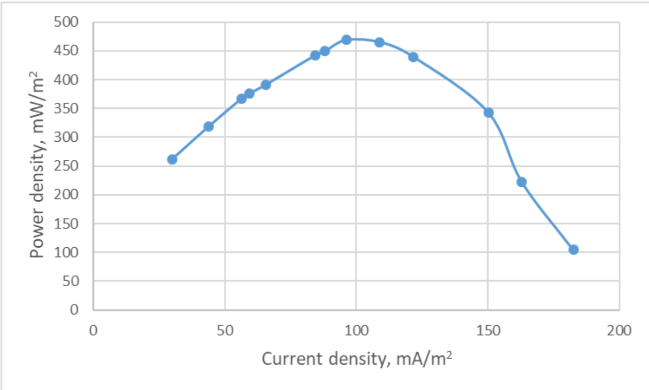


***Fig. 6*** *Power density dynamics when connecting 12x12 segments (SMFCs) in series and connecting two pairs in parallel*

With this connection, the composter achieved the best electrical parameters of the tested variants. A maximum power density of 474.6 mW/m$^2$ was recorded at a current density of 97.4 mA/m$^2$ and an applied resistance of 1.1 kΩ.

## *4. Conclusion*

Climate change, the growing need of the population and the economy for energy sources and the international commitments made to environmental protection require the research and implementation of innovative renewable energy sources. Plant waste is a raw material that is currently not sufficiently utilized and even creates prerequisites for environmental problems. Through appropriate technology implemented in working devices, plant waste can be a valuable source of renewable energy and value-added products, such as soil fertilizers.

Solid-phase microbial fuel cells are a suitable technology for the utilization of plant waste with parallel energy production. Studies in laboratory conditions show reliable results for practical application of the technology. In the present study, we integrated the solid-phase microbial fuel cell technology into a composter with cogeneration of energy through 24 stacked segments (SMFCs). The study of the composter's operation showed that 19 days after filling with plant biomass, the individual segments reach their maximum base voltage of an average of 728 mV. In order to establish the efficiency of the composter, three variants of electrical connection of the individual segments were studied. The results showed that a high power density of 474.6 mW/m2 with a series connection of 12x12 segments and a parallel connection of the two pairs.

In order to turn the constructed composter into a commercial product, additional research is needed on its long-term operation, the possibilities for storing and utilizing the generated energy, the quality of the resulting compost, etc. However, the data obtained are a step towards the possibility of using plant waste as a sustainable energy source.

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