UTILISATION OF GREEN WASTE FROM MINE OVERBURDEN THROUGH BIO-ELECTROCHEMICAL SYSTEMS

Rosen Ivanov

University of Mining and Geology “St. Ivan Rilski”, 1700 Sofia; E-mail: r.ivanov@mgu.bg

ABSTRACT. Proper management of overburden materials can reduce the environmental impact and increase the benefits of mining activities. It is important to consider the specific composition of the overburden and local needs when selecting the most appropriate recovery method. And while much of the overburden material can be used in construction, reclamation, cement production and more, the green waste problem has not been sufficiently solved. The present publication examines the possibilities of generating energy from the green waste from the overburden through bio-electrochemical systems. The possibilities of generating energy from grass, wood chips, and leaves have been investigated. The best results were achieved in grass utilisation, generating a power density of 107,58 mW/m^2.

Key words: mine overburden, bio-electrochemical systems, solid-phase microbial fuel cells

ОПОЛЗОТВОРЯВАНЕ НА ЗЕЛЕНИ ОТПАДЪЦИ ОТ ОТКРИВКАТА ЧРЕЗ БИО-ЕЛЕКТРОХИМИЧНИ СИСТЕМИ

Росен Иванов

Минно-геоложки университет „Св. Иван Рилски“, 1700 София

РЕЗЮМЕ. Правилното управление на материалите от откривката могат да намалят въздействието върху околната среда и да увеличат ползите от минно-добивните дейности. Важно е да се обмисли специфичния състав на откривката и местните нужди, когато се избира най-подходящият метод за оползотворяване. И докато голяма часто от материала на откривката може да бъде използван в строителството, за рекултивация, производство на цимент и други, проблемът със зелените отпадъци не е решен в достатъчна степен. В настоящата публикация са разгледани и изследвани възможностите за генериране на енергия от зелените отпадъци от разкривката чрез био-електрохимични системи. Изследвани са възможностите за генериране на енергия от трева, шредиран дървен материал и листа. При оползотворяването на трева бяха постигнати най-добри резултати, като се генерира плътност на мощността от 107,58 mW/m^2.

Ключови думи: откривка, био-електрохимични системи, твърдофазни микробни горивни клетки

Introduction

Underground mining of mineral ore requires the removal of an earth mass. In open pit mining, in particular, the volume of overburden generated during ore extraction can be very high. An overburden is a layer of soil, vegetation, and rock mass that must be removed to reach the ore being mined. Unlike the tailings, the overburden in most cases does not contain toxic components (Adibi et al., 2013).

The overburden material often finds direct application as sub-ballast in railway tracks, underlayment for asphalt pavements, aggregates (Mahamaya and Das, 2017), reclamation of terrains (Jambhulkar and Kumar, 2019), and others. Apart from those applications that have only focused on the direct use of mine overburden in various fields, overburden materials offer a high potential for conversion into a value-added product (Adibi et al., 2013).

In addition to soil and rock mass, the mine overburden also contains a large amount of vegetation. And unlike the mineral part of the overburden, the problem with the utilisation of green waste has not been solved to a sufficient extent (Spargo et al. 2016). Green waste is plant-based organic materials typically generated from lawn clippings, cut branches, fallen trees, leaves, plants, soil, and mulch. Green waste typically contains seeds, weeds and invasive plants that can enter and disrupt other ecosystems if disposed of inappropriately. These plants compete with native plants and degrade habitat quality, impacting biodiversity. Large piles of green waste can also suffocate small native plants and ground cover, affecting wildlife that rely on them for food and shelter. As green waste dries out, it creates a fire hazard, endangering neighbouring properties, infrastructure, and the environment. Green waste dumped into rivers or stormwater ditches affects water quality. Decomposition of organic material consumes oxygen and releases nutrients, which can lead to aquatic eutrophication and disruption of aquatic ecosystems. Green waste disposed of in this way can clog sewers and contribute to localised flooding (Smith and Aber, 2018). Piles of green waste threaten the landscape and affect the values and amenities of natural areas. The material can also serve as a breeding ground for pests. The costs associated with the removal and disposal of green waste can be a considerable problem (Chiu et al., 2016).

Recently, renewable bioenergy has been seen as one of the ways to ease future fuel needs and overcome the global warming crisis. Microbial fuel cell-assisted bioelectricity generation through the degradation of organic matter has attracted considerable interest in both fundamental and applied research in recent years (Utomo et al., 2017).

A microbial fuel cell (MFC) is a device that uses bacteria to directly convert chemical energy stored in organic matter into electricity through electrochemical processes. MFCs can be fed with liquid-phase substrates, such as domestic wastewater and industrial wastewater. Solid-phase microbial fuel cells (SPMFCs) can be fuelled with solid-phase organic wastes such as sludge, sediments, and vegetation. (Song and Aber, 2018) In this configuration, the cathode is usually exposed to the ambient oxygen in the air or immersed in water, while the anode is placed under anaerobic conditions in the solid-phase organic matter at the bottom of the cell. SPMFCs can be used as power sources for long-term environmental monitoring devices due to their simple design and solid organic matter providing a long-term power source (Venkata and Chandrasekhar, 2011).

Biodegradable organic matter present in green waste can be efficiently used to generate energy in the form of bioelectricity by the utilisation in solid phase microbial fuel cells. If properly designed, an SPMFC can facilitate the direct conversion of solid waste to energy and, therefore, make the process sustainable for waste management and recovery (Logrono et al., 2015).

In recent years, SPMFCs have emerged as a promising but challenging waste-to-energy technology, besides their treatment, gaining increasing importance due to their sustainable nature. This process offers the dual benefits of waste treatment and providing access to cheap and environmentally friendly energy (Mochamad et al., 2021).

This research aims to optimise the use of mine overburden waste by transforming it into value-added products and ensuring comprehensive and sustainable utilisation of green overburden waste.

Materials and methods

Construction of a solid-phase microbial fuel cell

The construction of the bio-electrochemical system for the experiment shown in Figure 1 is based on a single-chamber solid-phase microbial fuel cell (SPMFC). The solid-phase microbial fuel cell is a plastic container with a volume of 800 cm^3. At the bottom of the vessel is a graphite electrode with an area of 30 cm^2. The vessel was filled with organic green waste with a volume of 600 cm^3. The cell was then filled with pure water and a second 30 cm^2 graphite electrode was placed in the surface layer of the water. Graphite electrodes were chosen due to their higher porosity and specific surface area, an advantage for the adherence and growth of electroactive microorganisms.

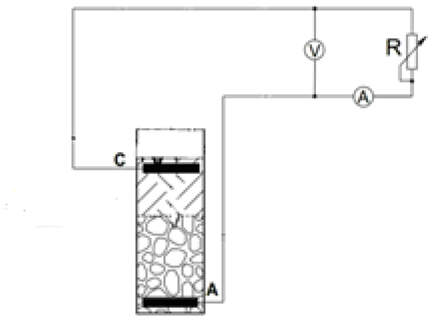

Fig. 1 Solid phase microbial fuel cell schematic diagram
A – anode, C - cathode

Solid-phase waste matter composition

Three identical solid-phase microbial fuel cells were made. The first one was filled with grass, the second was filled with leaves, and the third was filled with shredded wood (wood chips). 50 cm^2 of soil was added to each of the three cells. In this way, the cells were inoculated with an additional amount of electroactive microorganisms, naturally living in the soil (*Geobacter*, *Clostridium, Bacillus, Pseudomonas,* and others*)* *(Bratkova et al., 2018).*

Measuring of cell electrical parameters

For the polarisation curve test, the anode and cathode in the SPMFC were connected to a varied resistance box MCP lab electronics BXR-04 ResistorBox, and the stable voltages were recorded under varying external resistances (Wang et al., 2013) sequentially from 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1.5, 1.3, 1, 0.7, 0.5, 0.3 to 0.1 KΩ. Voltages produced from the SMFCs during the experiments were recorded at 60-min intervals using a *Vernier LabQuest Mini* and *Logger Lite* software.

Power was calculated according to *P=IU*. Current density and power density were calculated based on the anode area. The Ag/AgCl reference electrode was positioned near the cathode in order to measure the cathode potential. Anode redox potentials were approximated by subtracting the cell potential from cathode potentials (Song and Jiang, 2011).

Results

The goal of this study is to integrate a microbial fuel cell with solid-phase plant organics using the composting process to generate energy. As seen in Figure 2, the voltage of all SPMFCs was low during the first 3 days of the experiment, but then increased rapidly. This may be due to the formation of an active biofilm on the surface of the electrodes (Venkata and Chandrasekhar, 2011).

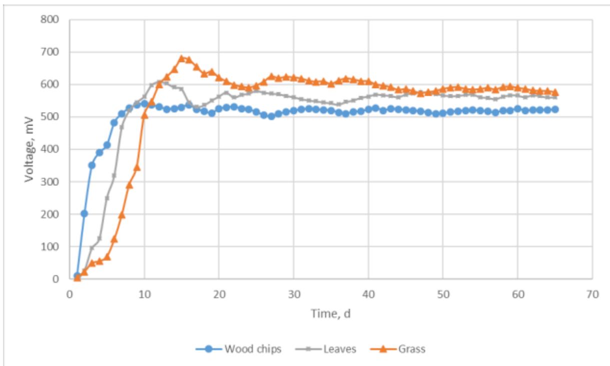

Fig. 2 Open-circuit voltage generation from SPMFCs containing green waste

SPMFCs reached their maximum voltage between day 8 and 14, remaining constant with slight fluctuations until day 65 of the experiment. The highest open-circuit voltage is generated by the SPMFC with grass. The cell reaches a maximum voltage on the 15th day (679 mV), then drops to 600 mV ± 24 and remains within these limits until the end of the experiment. The SPMFC with leaves generated a slightly lower open-circuit voltage and after the 20th day, it remained around 565 mv ± 6 until the end of the experiment. The lowest open-circuit voltage was generated by the SPMFC with wood chips. After stabilisation, the voltage during the experiment was in the range of 521 mV ± 10.

Figure 3 shows the polarisation curves of the three solid-phase microbial fuel cells.

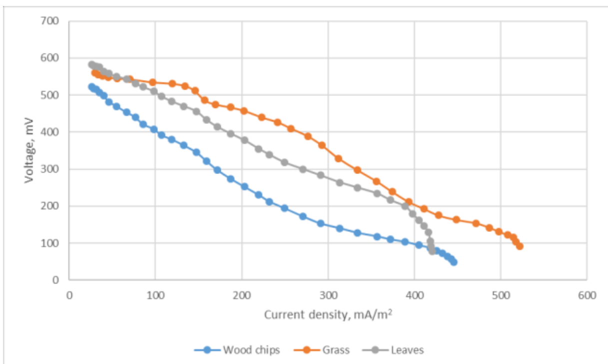

Fig. 3 Polarisation curves of SPMFCs containing green waste

The obtained graphs show close electrical parameters of SPMFCs with grass and of that with leaves. However, the solid-phase microbial fuel cell with grass shows the best results in terms of generated voltage and current density. A SPMFC with wood chips is characterised by the lowest value of the measured electrical parameters.

The power density curves of the SPMFCs were obtained on day 28 and are presented in Figure 4.

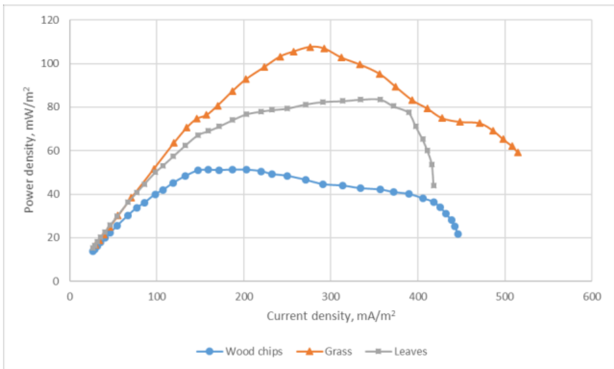

Fig. 4 Power density (data from polarisation curves) of SPMFCs containing green waste

The results in Figure 4 show that different organic substrates have different electrical characteristics in a solid-phase microbial fuel cell. This is most likely due to the different carbon/nitrogen ratio (Khudzari et al., 2016). The highest power density was achieved in the SPMFC with grass. A maximum power density of 107.58 mW/m^2 was obtained with this cell. A lower maximum power density was achieved for the SPMFC with leaves: – 83.51 mW/m^2. In the SPMFC with wood chips, the lowest power density of 51.21 mW/m^2 was obtained.

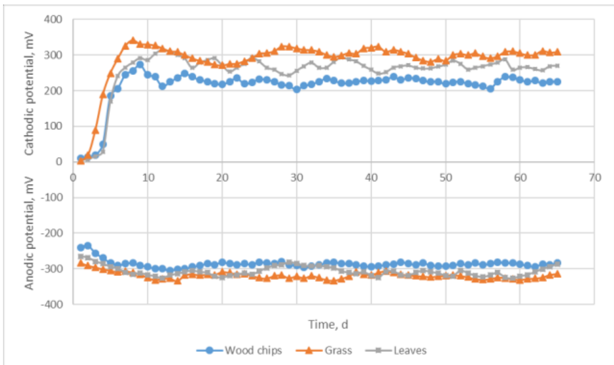

Fig. 5 Working potential of cathodes and anodes of SMFCs containing green waste

The results for the anodic and cathodic potentials relative to the Ag/AgCl reference electrode are presented in Figure 5. The cathodic potentials in the SPMFCs remained relatively constant throughout the experiment after cell stabilisation. The different patterns of cathode potentials of SPMFCs may be due to the rate of biofilm formation on cathodes, which resulted in different electrochemical characteristics of cathodes in SPMFCs. The SPMFC with grass maintained the highest cathodic potential of 300 mV ± 20 throughout the experiment. A slightly lower cathode potential was maintained in the leaf SPMFC. In this variant, the cathodic potential after stabilisation of the cell was in the range of 270 mV ± 23. The lowest cathode potential was measured in the SPMFC with wood chips. During the experiment, it moved in the range of 210 mV ± 14.

Anodic potentials in all SMFCs varied only slightly, ranging around from -280 to -330 mV, whereas the cathode potentials showed significant differences. The initial anodic potentials of the SPMFCs containing the green waste were negative (about -300 mV) and remained stable throughout the experiment.

Conclusion

Materials from mine overburden can seriously disturb the balance in the ecosystems where they are deposited. The mineral part containing in overburden can be widely used, and a number of studies have been carried out on its utilisation and on the reduction of its harmful impact on the environment. This is not the case with vegetation that is removed from the terrain prior to the commencement of mining or construction activities. Improper disposal can lead to disruption of natural biodiversity and ecosystems and to pollution of environmental components.

The present study showed the possibility of utilising the green waste from the overburden by generating energy from it in solid-phase microbial fuel cells. All three investigated organic substrates – grass, leaves, and wood chips – showed that they can be a long-term source of energy. However, the SPMFC with grass showed the highest electrical performance in terms of generated voltage – 600 mV ± 24 and power density – 107.58 mW/m^2. The lowest values of the electrical parameters were measured for the solid-phase microbial fuel cell with wood chips – a voltage of 521 mV ± 10 and a power density of 51.21 mW/m^2. Between 8 and 14 days were required to reach the full potential of SPMFCs, due to processes related to biofilm formation of electroactive microorganisms on the electrodes and degradation of organic matter. After stabilising the SPMFCs, the cells maintained a constant voltage throughout the experiment.

The results obtained are an advance in research for the development of bioenergy sources. Further research is needed on various factors influencing the energy generated from green waste, such as the optimal carbon/nitrogen ratio, the use of cellulose-degrading enzymes, inoculation with electroactive organisms, and others (Wang et al., 2015). It is also necessary to conduct additional experiments related to the possibilities of storing and converting the generated energy.

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