

Streszczenie w języku angielskim

Underground Coal Gasification (UCG) is an innovative technology that converts coal directly into syngas on site, minimizing the need for conventional mining and reducing the negative impact on the environment and occupational health. However, this process produces wastewater containing complex organic pollutants such as BTEX, polycyclic aromatic hydrocarbons (PAHs) and phenols, as well as inorganic pollutants including heavy metals. Due to their toxicity and the varying composition of the wastewater, the effective treatment of such wastewater poses a major technological challenge.

The aim of this study was to develop sustainable methods for treating wastewater from UCG by using wetland systems and hybrid technologies that integrate physico-chemical and biological processes. Physico-chemical, microbiological and toxicological analyses were performed on wastewater from different ex-situ experiments of UCG. The analyses revealed high concentrations of toxic organic compounds and heavy metals as well as a considerable variability in composition depending on the process parameters, such as the type of gasified coal and the gasification agent used. These pollutants were classified in the fifth toxicity class, thus emphasizing the need for advanced treatment methods.

In the first phase of the research, vertical flow columns were constructed with hydrophytes (e.g. *Phragmites australis*) and naturally occurring microorganisms. After 14 days of treatment, a significant reduction of the main organic pollutants was observed — over 95% of BTEX, PAHs and phenols were removed. At the same time, the toxicity of the wastewater was reduced by 74–99%, so that the treated wastewater could be classified as non-toxic (toxicity class I), which means that it does not harm the environment. These results confirm that wetland systems are an effective and environmentally friendly solution for the removal of organic and inorganic pollutants from UCG wastewater.

In the next phase of the study, the potential of improving wetland systems by integrating hybrid technologies, such as electrocoagulation and adsorption, was investigated. These systems showed effective removal of heavy metals and phenols. Both adsorption and electrocoagulation achieved heavy metal removal rates of up to 99.5% for cadmium, copper and nickel. Hybrid systems, especially those using adsorbents in wetland columns, showed greater flexibility and efficiency in removing various pollutants compared to stand-alone biological systems.

The study confirmed that wetland columns are an effective method for treating UCG wastewater, facilitating the biodegradation of toxic compounds through natural biological and

plant remediation processes. The results suggest that industrial-scale wetland systems and hybrid technologies can be used to treat various types of industrial wastewater, including wastewater from natural gas incinerators, coking plants and landfill leachate. In addition, studies on the microbiological activity of these systems have identified bacterial strains such as *Paenibacillus*, *Bacillus* and *Pseudomonas* that can degrade phenol. It has also been found that the formation of a biofilm on the surface of adsorbents increases the efficiency of biodegradation, while the use of isolated bacteria in bioaugmentation further improves treatment performance.

The conclusions from this study highlight the significant potential of wetland technologies and hybrid systems for the removal of toxic compounds from industrial wastewater. These systems are in line with the principles of circular economy and sustainable development. Their adaptability to different conditions and wastewater types makes them a key element in the energy industry's transition to more environmentally friendly technologies.