DOI: 10.5937/IOC25616P
Review paper

APPLICATION OF COPPER FOAMS FOR THE WATER PURIFICATION PROCESS

Ana Petrović[1a], Stefan Đorđievski[1b], Miloš Đukić[1c], Emina Požega[1d], Jelena Gligorijević Sokolović[1e], Dragana Adamović[1g]

[1] Mining and Metallurgy Institute Bor, Alberta Ajnštajna 1, 19210 Bor, Serbia
[1a] ana.petrovic@irmbor.co.rs, 0000-0002-9815-6884
[1b] stefan.djordjievski@irmbor.co.rs, 0000-0003-1737-8766
[1c] milos.djukic@irmbor.co.rs, 0000-0002-3307-4669
[1d] emina.pozega@irmbor.co.rs, 0000-0001-6797-2435
[1e] jelena.gligorijevic.sokolovic@irmbor.co.rs, 0009-0003-6713-760X
[1f] dragana.adamovic@irmbor.co.rs, 0000-0003-3683-4122

Abstract

Water contamination represents a critical global challenge, demanding safe and efficient purification technologies. Conventional disinfection methods such as chlorination, ozonation, and UV irradiation are limited by high energy demand and toxic by-products. In this study, a novel nanocomposite material, three-dimensional copper foam modified with Ag nanoparticles and CuO nanowires, was investigated for antibacterial activity. The material demonstrated strong efficiency in removing Escherichia coli and Staphylococcus aureus, achieving up to 99.9% removal under optimized conditions. Results indicate that bacterial elimination improves with voltage intensity and decreases with flow rate, confirming the nanocomposite's potential for practical water purification applications.

Keywords: *metal foams, wastewater, copper foams*

1. INTRODUCTION

Water contamination from industrial effluents, agricultural runoff, and microbial pathogens presents a growing global challenge, necessitating innovative, sustainable treatment strategies. Conventional methods such as chlorination and UV disinfection often entail high operational costs and generate toxic by-products, prompting research into novel materials with multifunctional capabilities [1]. Among these, copper foams have emerged as promising candidates due to their open-cell, high-porosity structure and superior conductivity, which enhance pollutant contact efficiency and support electrochemical treatment processes [2].

With porosity often exceeding 85–95% and specific surface areas reaching 5,000–10,000 m^2/m^3, copper foams facilitate effective adsorption, filtration, and electrochemical degradation of contaminants, while their natural antibacterial properties, stemming from the controlled release of Cu^{2+} ions, significantly reduce microbial load including E. coli and S. aureus. Moreover, copper's robustness under diverse environmental conditions translates to prolonged material life spans—often several times longer than activated carbon—resulting in reduced maintenance and operational costs [1,2].

Morphological studies using scanning electron microscopy (SEM) reveal copper foam's intricate networks of interconnected struts, high pore interconnectivity, and variable pore sizes, optimizing flow dynamics and surface interactions [2]. Beyond microbial inactivation, modified copper foams (e.g., superhydrophobic variants) demonstrate high efficiency for oil–water separation, achieving over 95% separation and maintaining stability under thermal and chemical stress [3].

Building upon these advantageous properties, this paper examines the application of copper foams in water purification, focusing on mechanisms of pollutant removal, and material durability. The aim is to highlight copper foam's potential as an effective, cost-efficient solution for future water treatment systems.

2. APPLICATION OF METAL FOAM FOR WATER PURIFICATION PROCESS

Water pollution and therefore the lack of clean water, occurs as a consequence of economic development. It is an important global issue that must be seriously considered, because the life and health of people and animals are seriously endangered. Contaminated water can transmit diseases such as diarrhea, cholera, dysentery, typhoid and polio. Over the years, many water purification technologies have been developed in order to overcome this problem. Some of the methods currently used for water disinfection are chemical or physical treatments: chlorination, ozonation, ultraviolet (UV) radiation, reverse osmosis and advanced oxidation processes. One of the major disadvantages of traditional water disinfection methods is the carcinogenic by-products, which are formed primarily during the chlorination and ozonation of water. On the other hand, the UV water disinfection method consumes a large amount of energy [4].

Electroporation sterilization technology is a new method for water disinfection. This method has been shown to be very effective against bacteria and viruses. One of the important advantages is that it does not produce harmful by-products because chemical impurities are not involved in the process. However, the energy consumption during electroporation disinfection can be enormous, therefore it cannot be applied to disinfect large volumes of contaminated water. Another limiting factor for their practical application is the low speed of the water treatment process [5].

A group of researchers [1] developed a new composite material, a 3D copper foam co-modified with Ag nanoparticles-CuO nanowires. The copper foams were purchased from the Chinese company Shanghai Macklin Biotechnology Co. The main components of the nanocomposite are Cu, Ag and O. The preparation of the nanocomposite based on copper foams was carried out in two steps. The first step consists of preparing CuO nanowires in a mixture of NaOH and $(NH_4)_2S_2O_8$ for 10 minutes at 40°C, followed by heating them in air at 180°C for 3 hours. The thus prepared CuO nanowires were grown on Cu foam by a wet chemical process. In order to remove oxides on the surface, the Cu foam was immersed in 1.0 M HCl solution for 2 minutes, then rinsed with deionized water and dried using high-purity N_2. The second step involves immersing the thus prepared copper foam in a plating solution (pH 7.5) at room temperature to deposit Ag nanoparticles. The solution contains $AgNO_3$ (3.5 g L^{-1}), $[(NH_4)_2S_2O_3]$ (25 g L^{-1}) and $(K_2S_2O_5)$ (3.5 g L^{-1}). The coating of copper foam with Ag nanoparticles lasted for 30 s, at a cathodic current density of 0.1 A dm^{-2}. Heating in air at 180°C for 1 h completes the preparation of the nanocomposite. The aim of this study was to investigate the efficient removal of gram-negative Escherichia coli (E. coli) and gram-positive Staphylococcus aureus (S. aureus) from water. The bacteria were cultured for 12 h, and by diluting with NaCl 9.0 g L−1, different concentrations of the solution were obtained in the range of 102 to 108 colony units per mL. The nanocomposite was placed in a filter device with two parallel electrodes under a voltage of 10 V. The colony count (CFU) method was used to calculate the bacterial removal.

Figure 1 shows a graph of the dependence of the removal rate of E. coli and S. aureus, using the prepared nanocomposite, on the applied voltage, liquid flow rate and bacterial concentration. As can be seen in Figures 2a and d, with increasing voltage, the removal rate of E. coli and S. aureus also increases. Based on this, it can be concluded that the stronger the electric field, the more effective the disinfection will be. Also, a comparison is given in the efficiency of bacterial removal using the nanocomposite and CuO nanowires without the addition of Ag. While the nanocomposites show disinfection performance even in the absence of an applied voltage, CuO does not have the ability to disinfect without an applied voltage, which indicates that Ag is responsible for killing bacteria. After applying voltage, disinfection was significantly improved. The maximum removal of E. coli and S. aureus was achieved at a voltage of 10 V and was 97.77% and 99.87%, respectively. The effect of fluid flow rate on the bacterial removal rate is shown in Figure 1b and e. In real water treatment processes, the water flow rate is usually 1–5 L min^{-1}, to

ensure effective water sterilization and reasonable energy consumption. In contrast to the previously discussed parameter, with the increase of flow rate, the removal rate of E. coli and S. aureus decreases. When the flow rate was 0.5 L min−1, both the nanocomposite and CuO nanowires had 99.9% removal of E. coli and S. aureus. By increasing the flow rate to 2 L min^{-1}, the nanocomposite maintains a bacterial removal rate of 75%, while on the other hand, CuO nanowires show poor disinfection performance. Figure 1c and f show a graph of the bacterial removal rate as a function of bacterial concentration. The highest removal rate of E. coli and S. aureus for both materials is 99.9%, at a bacterial concentration of 102 CFU mL^{-1}.
The disinfection efficiency of the nanocomposite is not significantly affected by the change in the concentration of bacteria in the solution, while in the case of CuO nanowires it is clearly observed that the rate of removal of bacteria decreases with increasing concentration of bacteria [1].

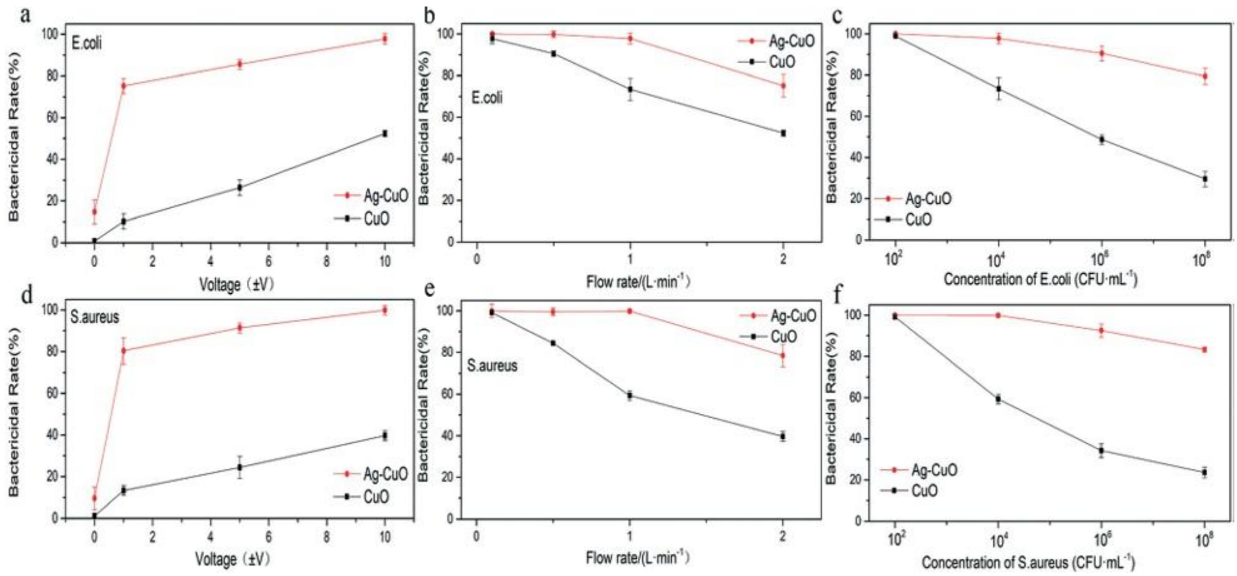

Figure 1.E. coli and S. aureus removal efficiency in the flow test: (a) and (d) effect of voltage; (b) and (e) effect of flow rate; (c) and (f) effect of E. coli (S. aureus) concentration [1]

The results show that the nanocomposite has a high sterilization effect, with a rate higher than 99.9% at a liquid flow rate of 1 L min^{-1} and has significant potential for practical application. However, in water heavily contaminated with bacteria, the nanocomposite would not maintain high bacterial removal efficiency unless a high voltage was applied [1].

4. CONCLUSION

The earth is continuously contaminated with numerous toxic substances from both natural and anthropogenic sources. Rapid population growth and increasing industrial development have caused the release of various toxic elements, compounds or materials into the environment. Many new chemicals are used without proper assessment of their environmental risks and effects on human health. The discharge of untreated industrial wastewater into water and soil, the use of pesticides and fertilizers in agriculture, the inadequate use of harmful chemicals in consumer products and the burning of fossil fuels are some of the main causes of water pollution. Due to the increasing consequences caused by polluted waters, the scientific community has a responsibility to develop effective technologies to prevent further contamination of the environment [4].
So far, great progress has been made in the study of metal foams as adsorbents of heavy metals and polluting components from the aquatic environment. In this paper, emphasis is placed on metal foams based on copper, because they are adsorbents that are easy to face the growing challenges of environmental protection, especially bacteriological remediation of water. Copper foams offer numerous advantages over other adsorbents and possess unique properties, including stiffness,

light weight, and the most important feature of metal foams is their low density. The development of cheap and efficient adsorbents is an imperative in current research, because it is necessary to take into account the cost factor in order to enable the mass application of adsorbents [2].
Based on previous experiments, copper foams have proven to be excellent adsorbents for bacteria (fungi, algae and molds), especially E. coli and S. aureus. Their effectiveness depends on a number of parameters such as the initial concentration of the polluting component, the flow rate, the density of the applied Cu foam, the voltage at which the adsorption process takes place and the time of contact between the adsorbent and the treated solution. In lakes, rivers and oceans, the application of Cu foam is not a widely applied technology for water pollution control, because despite the good results of experiments at the laboratory level, the technology has not yet been fully explored. An environmental and human health risk assessment should be carried out before mass application, as metallic foams often have toxic effects on aquatic organisms when applied in high concentrations [1].

ACKNOWLEDGEMENTS

This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract on realization and financing of the scientific research work of the Mining and Metallurgy Institute Bor in 2025, contract number: 451-03-136/2025-03/ 200052.

REFERENCES

[1] L. Yue, S. Chen, S. Wang, C. Wang, X. Hao, Y.F. Cheng, Environ. Sci., Nano 6 (9) (2019) 2801–2809.
[2] M. Oruc, R. Sunulahpašić, Savremeni metalni materijali, Fakultet za metalurgiju i materijale, Univerzitet u Zenici, Zenica, 2005, p.151-163.
[3] A. Baxevani, F. Stergioudi, N. Patsatzis, L. Malletzidou, G. Vourlias, S. Skolianos, Coatings 13 (2) (2023) 355.
[4] T. Manasfi, in Comprehensive Analytical Chemistry (T. Manasfi, J. L. Boudenne), Elsevier, Amsterdam, 2021, p. 85–116.
[5] J. Zhou, Y.C. Hung, X. Xie, Wat. Res., 207 (2021) 117817.