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Exploring water disinfection through electrolytic ozonation for application in wartime conditions

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Abstract. Clean and safe water is a fundamental requirement for human survival and well-being. The destruction of civilian infrastructure during wars or natural disasters can severely limit access to clean water for the local population, military, rescue workers and volunteers. The objective of the study was the evaluation of the efficiency of fresh water disinfection by electrolytic ozonation. The ozone concentration was measured photometrically by the intensity of the colour change in the reaction with N, N-diethyl-p-phenylenediamine sulfate. The water quality was assessed microbiologically by determining the total microbial count of the samples and by analysing the colour of the bottom of the flasks in which the water samples were stored. The efficiency of ozonation of artesian water in the field was evaluated. Electrolytic ozonation of 500 mL of spring water for two and five minutes produced an aqueous ozone solution with a concentration of 0.74 and 1.72 mg/L, respectively. Electrolytic ozone decomposed slowly and was detected in the samples three days after the water treatment. Ozonation of spring water for 5 and 10 minutes effectively inactivated all natural microorganisms (2.11 log CFU/mL), the water remained sterile and without any colour changes for a month. Water samples ozonated for 2 minutes did not demonstrate any visible changes after a month of storage, however the natural microflora partially recovered. Planktonic microorganisms in the amount of 2.33 log CFU/mL, as well as biofilms on the walls of the flasks, were detected in a month in the control water samples. The colour of the bottom of the control flasks changed to dirty yellow. In the field, ozonation of water for 10 minutes prevented its spoilage even when the recommended treatment volume was increased by 10 times. The obtained results indicate that electrolytic ozonation is an effective method of freshwater disinfection, and portable ozonators can play an important role in emergency water purification in areas of armed conflicts or natural disasters

Keywords: ozone; water disinfection; inactivation of microorganisms; portable ozone generator; armed conflict

INTRODUCTION

Clean water is an essential resource for both human life and various industries. Military operations can have a significant and detrimental impact on water quality for residents in active conflict zones due to the destruction of water supply and wastewater infrastructure, including water treatment plants, distribution systems, and sewage

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facilities. Russia's war against Ukraine has significant environmental consequences [1], especially for Ukrainian water resources [2].

Ensuring access to clean water is of utmost importance for civilians, the military, rescuers, and volunteers in areas with destroyed civilian infrastructure. In emergency water disinfection, the military may resort to chlorine-containing tablet disinfectants. However, as it has been stated by L.B. Cahoon [3] despite their low cost, these disinfectants may not be readily available to the civilian population and could pose risks due to the formation of toxic or carcinogenic chlorination by-products. The formation of disinfection by-products associated with a potential heightened risk of bladder cancer, along with other adverse reproductive health effects, have been reported by M. Lindmark *et al.* [4]. An alternative for emergency water disinfection is the use of ozonation. Ozone is a powerful oxidant with strong antimicrobial properties [5]. D. Zheng *et al.* [6] reported that by its properties, ozone is a stronger oxidizing agent than molecular oxygen or hydrogen peroxide and reacts with most substances at room temperature. C. Chuwa *et al.* [7] documented that ozone can effectively inactivate bacteria, viruses and other pathogens present in water, in fruits, vegetables, meat, grains, and their products. Traditionally, water ozonation involved bubbling ozone gas through water, necessitating the use of costly high-performance industrial ozonators [8] and adherence to safety regulations. As reported by E. Grignani *et al.* [9] gaseous ozone, upon contact, can irritate the eyes, skin, and mucous membranes. Residual gaseous ozone must be neutralised by thermal or catalytic destructors [10]. In addition, the traditional method of creating ozone involved the use of concentrated oxygen, which poses explosive risks. E.I. Epelle *et al.* [11] reported the utilization of electrolysis to saturate water with ozone, bypassing the dangerous gaseous phase. Consequently, there is an urgent need for the development of portable, energy-saving, and, most importantly, safe devices for water disinfection. These devices are crucial for deployment in wartime, natural disasters, daily life, and within medical and veterinary institutions.

This study focuses on evaluating the effectiveness of such portable devices, utilizing an electrolytic method to saturate water with ozone. Powered by low-voltage (5 V) sources, these devices are designed for emergencies, providing a swift and efficient means of water disinfection. The purpose of this study was to further investigate the effectiveness of electrolytic ozonation for disinfecting fresh water, with a focus on assessing the long-term impact of ozonation on the quality of drinking water.

MATERIALS AND METHODS

This study is a continuation of previous research [12] focused on the disinfection of fresh water by electrolytic ozonation.

Water samples and duration of the experiment. To test the effectiveness of long-term water disinfection with electrolytic ozone, samples of spring water were collected (Hai-Hrechynski village, Ternopil district). Water samples taken on the day of the experiment were collected directly from the stream into sterile 300 mL flasks and then delivered to the laboratory. Some samples were used for short-term experiments (ozone concentration measurements). The other part was left after treatment to study the long-term effect of ozonation (bacteriological and colour analysis). To maximise natural light, the treated and untreated water samples were stored at room temperature (20 ± 2°C) on the windowsill of an east-facing window for one month (from mid-November to mid-December 2023).

Water treatment conditions. Water ozonation was performed with a commercial portable ozoniser (the manufacturer is not specified at the request of the equipment owner to avoid advertising) by saturating water with ozone obtained by electrolysis [13]. The production scheme and the equation for ozone formation are depicted in Figure 1.

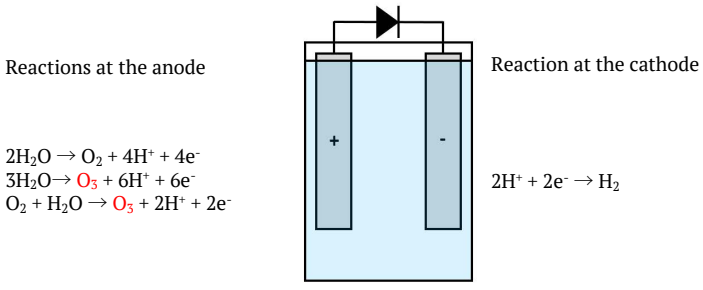

Figure 1. Principle of operation of the ozonator, illustrating chemical transformations
Source: scheme – compiled by the authors. Chemical equations adapted from F. Okada & K. Nay [13]

The manufacturer specifies an initial ozone concentration ranging from 0.8 to 1.3 mg/l, depending on the duration of ozonation. Two modes of electrolytic ozonation of water, lasting 2 and 5 minutes (referred to as Mode 1 and Mode 2), were installed by the manufacturer. In the experiments measuring ozone concentration dynamics, both o zonation modes were tested. For experiments involving the long-term preservation of water, two modes were applied as well as an ozonation extended to 10 minutes, achieved by repeating the second mode twice. Before

each experiment, the working part of the ozonator was rinsed with sterile distilled water. Disinfectant solutions were avoided to prevent any impact of residual disinfectants on the results. Throughout ozonation, water stirring was employed to ensure uniform ozone saturation.

Measurement of ozone concentration in aqueous solution. The concentration of ozone in water was measured photometrically using a PoolLab 1.0 photometer (Water-i.d., Eggenstein, Germany) by the intensity of the colour change in the reaction with N,N-diethyl-p-phenylenediamine sulfate [11]. The ozone concentration was determined by the absorption of coloured light (wavelengths of 530 and 620 nm) by the sample compared to the untreated sample using the calibration data programmed into the instrument. The photometer used in this study has an ozone measuring range of 0-4 mg/L and uses three wavelengths (530/570/620 nm) to measure the concentration of ozone and other substances in water. Tablet-based reagents were used for measuring ozone concentration, with each measurement taking approximately 3 minutes per sample. To determine ozone concentration, 500 mL of spring water samples were ozonised in individual sterile measuring cups. Measurements were conducted at room temperature (20°C) every 20 minutes for the initial hour, followed by daily measurements until the ozone concentration reached 0 mg/L.

Microbiological study. To assess the efficacy of water disinfection, both treated and untreated (control) water samples were subjected to decimal serial dilutions in sterile 0.9% NaCl solution. Subsequently, aliquots were combined with nutrient agar (Sanimed-M LLC, Kharkiv, Ukraine) that had been melted and cooled to 50°C. For this process, 1 mL of dilutions and undiluted samples were plated in sterile Petri dishes (Sarstedt, Inc., Numbrecht, Germany). Ten to twelve millilitres of nutrient agar, melted using a water bath (Biosan WB-4MS, BioSan SIA, Riga, Latvia), were added to each plate and mixed by gently shaking. Following agar solidification, the plates were incubated at 30°C for 72 hours, after which colony-forming units (CFU) were counted. The study was conducted both at the beginning and the end (1 month) of the experiment.

Colour change analysis. Colour change analysis was employed to evaluate visible signs of water spoilage. For this purpose, water samples in bottles were photographed using a Nikon D3200 camera (Nikon Corporation, Tokyo, Japan) with a Nikon DX 18-55 mm 1:3.5-5.6 lens. The photographic process occurred at the onset and conclusion (after 1 month) of the experiment indoors under artificial lighting from an arc mercury gas-discharge fluorescent lamp. Accurate colour reproduction was ensured by calibrating to the X-Rite ColourChecker Passport palette using the ColourChecker Passport software (X-Rite Inc., Grand Rapids, Michigan, USA). Colour changes in the samples were analysed on a selected 10 × 10-pixel squares using the free online software Image Colour Extract [14] and the obtained values of the dominant colour were expressed in the CIELAB colour space. Here, the parameter "L*" denotes lightness, while "a*" and "b*" denote colours. In this context, "a*" indicates the ratio of the green and red components of the colour [(-) – green, (+) – red], and "b*" represents the ratio of the blue and yellow components [(-) – blue, (+) – yellow].

The application of water ozonation in "field conditions" by volunteers in southern Ukraine aimed to address the demand for drinking water. In June-July 2023, groups of volunteers in the Kherson region utilised the same portable ozonisers, totalling 20 units, as part of an operation to assist flood victims after occupation forces detonated the Kakhovka hydroelectric power station dam. The water, sourced from artesian wells in the Buchak aquifer, underwent treatment directly in water containers (5-litre PET bottles). Ozonators were powered by portable solar panels or portable chargers (output voltage: 5 V, current: 3 A).

Statistical analysis. All experiments, except for the colour change assay, were conducted in triplicates. The number of CFU was expressed in logarithmic values. The mean values and the standard deviations were calculated ($M \pm sd$) and utilised for statistical purposes. The equality of mean values in two samples was assessed using Student's t-test. For comparisons among multiple groups, one-way analysis of variance (ANOVA) was employed, using Statistica 8.0 software (StatSoft Inc., Tulsa, Oklahoma, USA). Subsequently, Tukey's post hoc analysis was conducted to discern differences in mean values. Significance was determined at $p < 0.05$.

Ethics statement. The research protocol for this study was conducted under the principles outlined in the UNESCO [15]. The study design and procedures were approved by the Committee on Bioethics of I. Horbachevsky Ternopil National Medical University (Protocol No. 76, January 15, 2024), and all participants provided informed consent prior to their involvement in the study. Before participation, all volunteers were briefed on the nature and purpose of the study, as well as any potential risks or benefits involved. Measures were taken to ensure the safety and well-being of participants throughout the study, including appropriate training on the use of portable ozonators and access to necessary medical care in the event of any adverse events. Additionally, efforts were made to respect the autonomy and privacy of participants, and their personal information was handled confidentially following ethical guidelines.

RESULTS

Measurement of ozone concentration in aqueous solution. The studies revealed variations in the initial ozone concentration compared to the manufacturer's specifications. Specifically, the utilization of Mode 1 resulted in a solution with an ozone concentration of 0.74 ± 0.04 mg/L, while Mode 2 generated a concentration of 1.72 ± 0.18 mg/L (Fig. 2).

Measurements of ozone concentration every 20 minutes showed a decrease in each subsequent sample. After an hour, the ozone concentration in the water treated for 2 minutes was 0.55 ± 0.05 mg/L ($p < 0.05$), and in the water treated for 5 minutes – 1.53 ± 0.10 mg/L ($p > 0.05$). Subsequent measurements of ozone concentration revealed that it became undetectable in samples treated with Mode 1 by day 2-3, and with Mode 2 by day 4 (Fig. 3).

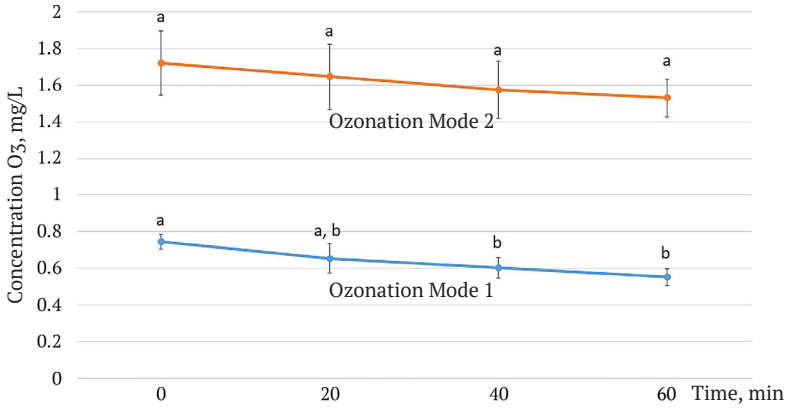

Figure 2. Changes in ozone concentration in aqueous solution after ozonation for 2 and 5 minutes over one hour
Notes: error bars indicate the standard deviation of the mean, and letters above the bars denote a significant difference ($p < 0.05$)
Source: compiled by the authors

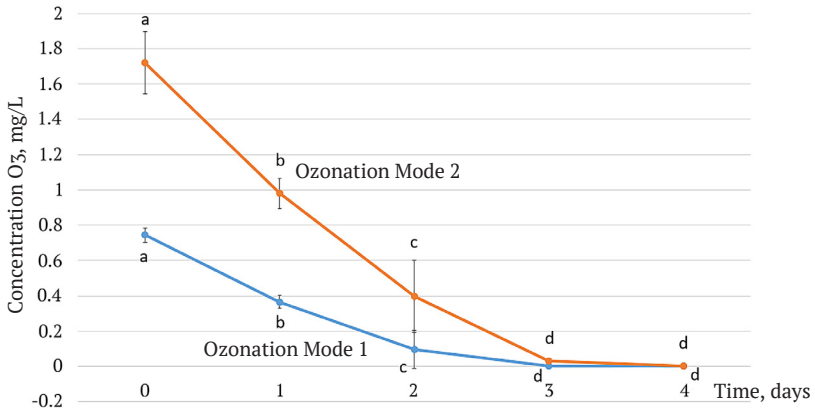

Figure 3. Long-term changes in ozone concentration
in aqueous solutions following ozonation for 2 and 5 minutes over a period of several days
Notes: error bars indicate the standard deviation of the mean, and letters above the bars denote a significant difference ($p < 0.05$)
Source: compiled by the authors

After storing the solution at room temperature for a day, the ozone concentration in water treated with Mode 1 was 0.37 ± 0.04 mg/L, while in samples treated with Mode 2, 0.98 ± 0.08 mg/L of ozone remained ($p < 0.05$). Within a day, the ozone concentration decreased to 0.10 ± 0.10 mg/L and 0.40 ± 0.08 mg/L ($p < 0.05$) for samples treated with Mode 1 and Mode 2, respectively. After 3 days, ozone at a concentration of 0.03 ± 0.01 mg/L ($p < 0.05$) was detected only in samples treated with Mode 2. In addition to photometric analysis, the samples were evaluated organoleptically, revealing that even at low ozone concentrations in water, the samples retained a specific ozone odour.

Microbiological study. Microbiological studies have demonstrated that ozonation significantly diminishes the number of microorganisms in spring water. The total microbial count (TMC) of control samples was 128.7 ± 14.5 (2.11 ± 0.05 log CFU/mL). Following ozonation treatment, only single microorganisms were detected, and this was observed exclusively in samples treated by Mode 1 (Table 1).

Table 1. Microbial counts in water at the start and end of the experiment (log CFU/mL)

Ozonation time	Microbial counts in spring water	
	start of the experiment (day 1)	end of the experiment (day 30)
2 minutes	0.61 ± 0.21	1.92 ± 0.26*
5 minutes	0	0
10 minutes	0	0
Control	2.11 ± 0.05	2.33 ± 0.11*

Notes: * – $p < 0.01$
Source: compiled by the authors

Storage of water samples for one month revealed a significant ($p < 0.01$) increase in the number of microorganisms in both control samples and those treated with Mode 1. However, visible signs of water spoilage were observed exclusively in control samples.

Assessment of visible signs of water spoilage. At the beginning of the experiment, the colour analysis revealed that the bottom of all flasks appeared grey. This was attributed to the absence of sediment, the transparency of the water and glass, and the shadow cast by the flask itself on a white background (Fig. 4).

Storage of water samples for one month revealed visible changes only in the control sample. Colour analysis indicated a shift of the "b*" parameter toward the yellow spectrum, resulting in a noticeable, dirty yellow colour of the sediment at the bottom. In contrast, the colour of the bottom in treated samples retained shades of grey similar to the initial conditions (Fig. 5).

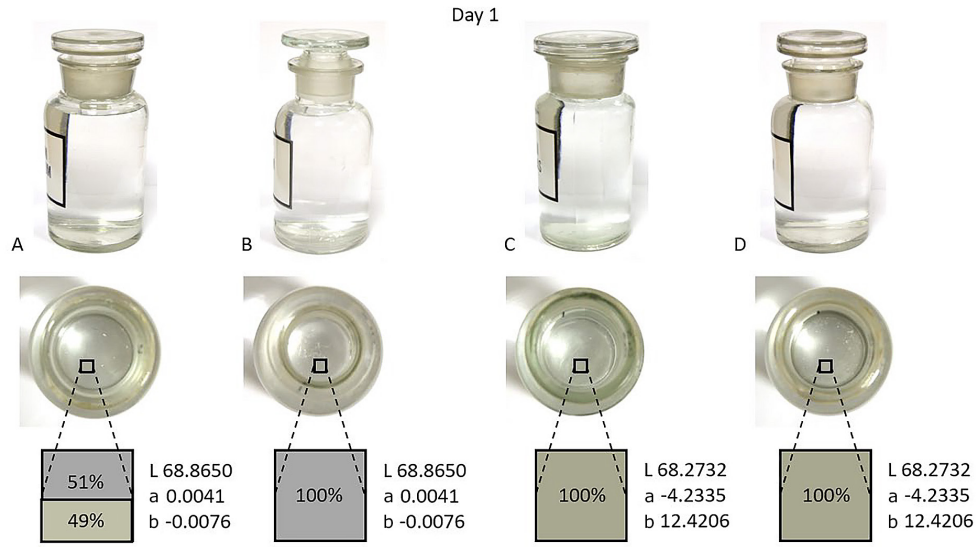

Figure 4. Colour analysis of the bottom of the flasks on the first day of the experiment
Notes: A – untreated sample (control); B – water treated with ozone for 2 minutes; C – water treated with ozone for 5 minutes; D – water treated with ozone for 10 minutes; L – lightness, a – ratio of the green and red components of the colour [(-) – green, (+) – red], b – ratio of the blue and yellow components [(-) – blue, (+) – yellow]
Source: compiled by the authors

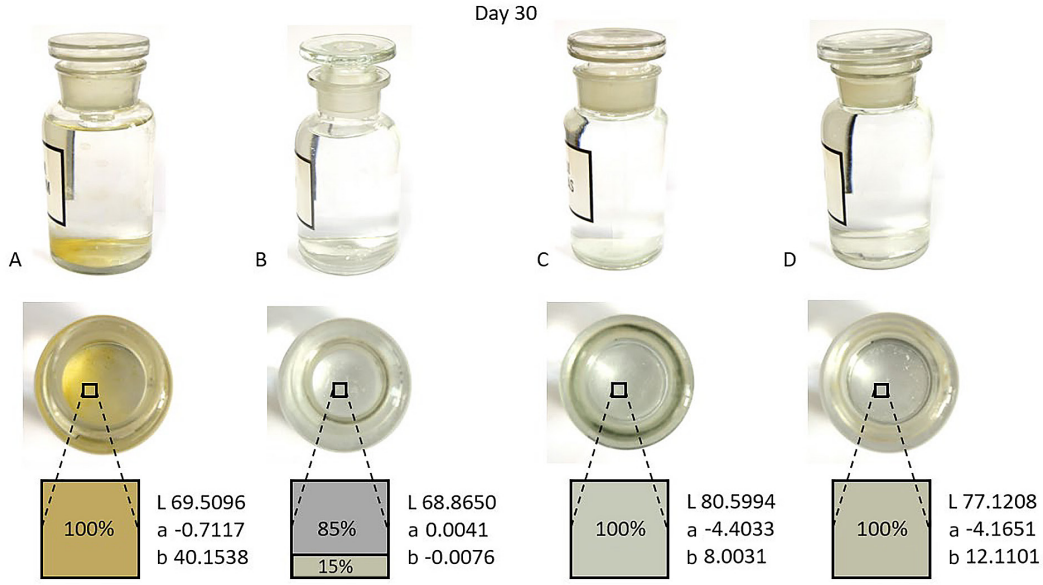

Figure 5. Colour analysis of the bottom of the flasks on the last day of the experiment
Notes: A – untreated sample (control); B – water treated with ozone for 2 minutes; C – water treated with ozone for 5 minutes; D – water treated with ozone for 10 minutes; L – lightness, a – ratio of the green and red components of the colour [(-) – green, (+) – red], b – ratio of the blue and yellow components [(-) – blue, (+) – yellow]
Source: compiled by the authors

Furthermore, after emptying the flasks, biofilms were observed on the walls of the control flask (Fig. 6). Inoculation of material from these formations on nutrient agar revealed bacterial growth. No biofilms were found in the treated water samples.

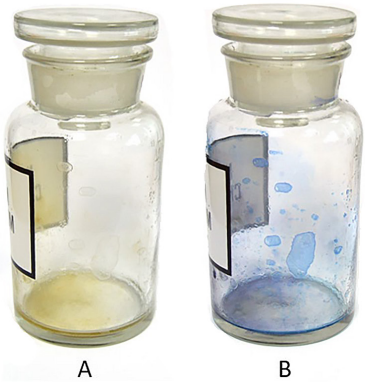

Figure 6. Biofilms on the walls of the flask
Notes: A – after emptying the flask; B – after staining with methylene blue
Source: compiled by the authors

These observations, combined with microbiological studies, affirmed the spoilage of water in the control sample and the preservation of water suitable for consumption in the ozone-treated samples.

The results of the application of water ozonation in "field conditions" by volunteers in southern Ukraine aimed to address the demand for drinking water. In the summer of 2023 (June-July), a group of volunteers in the Kherson region employed portable ozonators for water pretreatment. At times, the ozonators were powered by connecting them to residential electricity lines, but more frequently, the volunteers utilised either solar panels or portable chargers. The utilization of both solar panels and portable chargers afforded the volunteers flexibility, enabling them to operate the ozonators independently of residential electricity grids. The temperature in the Kherson region during these months exceeded 35°C. Water sourced from the Kyiv region (Buchak aquifer) rapidly deteriorated when stored in plastic bottles under warm, sunny conditions. Volunteers observed changes in colour (yellowing, greening) and an unpleasant smell. These alterations were attributed to the proliferation of cyanobacteria (resulting in greening and the development of an odour) [16] and the naturally elevated iron content in the waters of the Buchak aquifer (leading to yellowing) [17]. Upon applying ozonation for 10 minutes with portable ozonators (Mode 2 twice), the water remained potable for 2-4 weeks without visible signs of deterioration before complete use. According to volunteer observations, water that had turned yellow during storage regained its transparency after ozonation, and the unpleasant smell dissipated. The volunteers utilised the ozone-treated water for drinking, cooking, and personal hygiene. It's noteworthy that the volunteers, contrary to manufacturer instructions (which recommend a maximum ozonation volume of 500 mL), used portable ozonators in 5-litre PET bottles, exceeding the recommended volume by ten times.

DISCUSSION

The relatively slow decomposition of ozone was surprising, given that other authors have reported rapid decomposition in aqueous solutions, leading to the formation of molecular oxygen, hydroxyl radicals, and short-lived reactive oxygen species [18, 19]. E.I. Epelle *et al.* [11] reported a half-life of 10 minutes at 18°C for electrolytically produced ozone in drinking water. Similarly, Y. Hirahara *et al*. [18] observed a half-life of 39 minutes for electrolytic ozone in distilled water at 20°C. K. Varol [20] reported a half-life of 20 minutes for ozone in various water types, including ozonated drinking water, distilled water, and water for injection, in studies involving ozonation by bubbling. It's worth noting that M. Seki *et al*. [21] demonstrated a longer storage of ozone in an aqueous solution produced by nanobubble technology. In their research, commercially prepared ozonated water lost 90% of its ozone after a week at 25°C, while at 4°C, it retained 90% of its original concentration over the same time. The findings of the authors mentioned above are consistent with the results described in this manuscript, despite the technical differences in the types of ozonated water studied.

The ozone inactivation of microorganisms in spring water aligns with the findings of L. Meunier *et al*. [22], who demonstrated the inactivation of more than 5 log CFU of vegetative bacterial cells by bubbling an ozone-containing gas mixture through cooled drinking water. In the experiments conducted by the authors of this manuscript, water treated with ozonation for over 5 minutes remained bacteria-free for one month. This is similar to the findings of A.M. Gorito *et al*. [23] who explored the potential of preventing bacterial recovery in water through ozonation, albeit with more contaminated (6 log CFU/100 mL) (Note: units as per the original paper) river water. According to their results, 1.5 mg/L for 10 minutes neutralised all microorganisms, but after storing samples for 3 days at 37°C, live microorganisms were detected. However, increasing the ozone concentration to 3 mg/L prevented the recovery of microorganisms after treatment and storage.

The volunteers' observations regarding the restoration of the transparency of yellowed water align with the findings of T. Zhang *et al.* [24], who described the effective decolourization of water during ozonation by bubbling gaseous ozone (1.5-3 mg/L). The ozonation of municipal wastewater, in conjunction with flocculation, filtration, and ultraviolet treatment, was explored in their study. However, the results indicated limited effectiveness in removing odour-causing substances, prompting the additional recommendation of nanofiltration. X. Ren *et al*. [25] demonstrated a reduction of odour-forming substances (geosmin and 2-methylisoborneol) in open water by over 92% using ozonation by bubbling (2 mg/L) combined with filtration through granular activated carbon. The restoration of the transparency of yellowed water, as described by the volunteers, is consistent with the work of S. Tripathi & T. Hussain [26], who reported the oxidation of iron and manganese in water using ozone. Additionally, both laboratory findings and volunteers' observations are in line with the conclusions of T. Manasfi [27] who stated that while disinfection is frequently the primary objective of using ozone in drinking water treatment, additional applications encompass the removal of colour,

odour, and taste compounds, as well as the elimination of iron and manganese.

The prevention of biofilm formation on surfaces using ozonated water was also observed by M. Marino *et al*. [28]. They reported the inactivation of strains of microorganisms such as *Pseudomonas fluorescens*, *Staphylococcus aureus*, and *Listeria monocytogenes* in biofilms on the surface of stainless steel under both static and dynamic application of ozonised water, produced by the electrolytic method, with an ozone concentration of 0.5 mg/L. Additionally, J.C. Oliver *et al.* [29] observed the effective inactivation of *Pseudomonas aeruginosa* in biofilms on contact lens containers using distilled water saturated with ozone. In contrast, L. Zhang *et al.* [30] reported that stress induced by excessive ozonation resulted in more intensive biofilm accumulation of *Legionella* compared to lower doses of ozone.

The decentralised use of ozonation for water treatment in Western Kenya was detailed by C. Hendrickson *et al.* [31]. In their study, the authors employed solar panels to power ozonators, which sterilised contaminated groundwater stored in a 1000-litre tank. Their system incorporated flocculation and filtration methods prior to ozonation. Similarly to the portability of ozonators described in this manuscript, A. Hafeez *et al.* [32] described the utilization of lightweight (750 gm approximately) portable solar-powered non-thermal air plasma devices which could be fully charged and taken to remote areas or where a power source is not available. The conducted studies, in general, demonstrate the potential of electrolytic ozonation for extending the shelf life of water, both indoors and in the field.

CONCLUSIONS

This study aimed to evaluate the efficiency of freshwater disinfection through electrolytic ozonation, particularly in the context of emergency water purification in areas affected by armed conflicts or natural disasters. The results indicate that electrolytic ozonation effectively produced aqueous ozone solutions with concentrations suitable for disinfection purposes. Ozonation of 500 mL of spring water through electrolysis for two and five minutes resulted in aqueous ozone solutions with concentrations of 0.74 and 1.72 mg/L, respectively. Electrolytic ozone exhibited gradual decomposition, with detectable levels remaining in the samples three days following the water treatment. Ozonation of water for five and ten minutes successfully inactivated up to 2.11 log CFU/mL of natural microorganisms and prevented spoilage both in laboratory and field conditions, demonstrating its potential for ensuring the safety and availability of clean water in challenging environments. Furthermore, ozonation of water samples prevented the formation of natural flora biofilms, which were observed in control samples. The practical value of this work lies in its contribution to emergency response efforts, where access to clean water is essential for sustaining life and preventing disease outbreaks. By demonstrating the effectiveness of electrolytic ozonation in producing safe drinking water, this study offers a viable solution for addressing water sanitation challenges in resource-constrained settings, including those affected by conflict or disaster. Future research could explore further optimization of electrolytic ozonation processes to enhance efficiency and scalability, as well as investigate the long-term stability and safety of ozonated water. Additionally, studies examining the effectiveness of electrolytic ozone in preventing the formation of biofilms on various surfaces would be highly valuable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Дослідження знезараження води за допомогою електролітичного озонування для застосування в умовах воєнного часу

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Анотація. Чиста та безпечна вода є фундаментальною вимогою для виживання та добробуту людини. Руйнування цивільної інфраструктури під час воєн чи природних катастроф може сильно обмежити порушити доступ до чистої води для місцевого населення, військових, рятувальників та волонтерів. Метою дослідження було вивчення ефективності знезараження прісної води методом електролітичного озонування. Концентрація озону вимірювали фотометричним способом за інтенсивністю зміни кольору у реакції з N,N-діетил-п-фенілендіаміну сульфатом. Якість води оцінювали мікробіологічно, визначаючи загальне мікробне число зразків, та за допомогою аналізу кольору дна флаконів, у яких зберігалися зразки води. Оцінювали ефективність озонування артезіанської води у польових умовах. Електролітичне озонування 500 мл джерельної води протягом двох та п'яти хвилин створювало водний розчин озону у концентрації 0,74 та 1,72 мг/л відповідно. Озон утворений електролітично розпадався повільно і виявлявся у зразках через три доби після обробки води. Обробка озоном джерельної води протягом 5 та 10 хвилин ефективно знешкоджувала всі природні мікроорганізми (2,11 log КУО/мл), вода залишалася стерильною та без змін кольору протягом місяця. При озонуванні протягом 2 хвилин, через місяць видимих змін у зразках не наступало але частково відновлювалася природна мікрофлора. У контрольних зразках через місяць виявлялися планктонні мікроорганізми у кількості 2,33 log КУО/мл та біоплівки на стінках флаконів, а колір дна змінювався на брудно-жовтий. В польових умовах озонування води протягом 10 хвилин попереджувало її псування навіть при збільшенні рекомендованого об'єму для обробки у 10 разів. Отримані результати свідчать, що озонування електролітичним способом є ефективним методом знезараження прісної води, а портативні озонатори можуть відігравати важливу роль в екстреному очищенні води в зонах військових конфліктів чи природних катастроф

Ключові слова: озон; знезараження води; інактивація мікроорганізмів; портативний генератор озону; збройний конфлікт