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RESEARCH ARTICLE

RESEARCH OF THE SOLAR ENERGY-POWERED OZONATOR SYSTEM IN THE WATER PURIFICATION PROCESS

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ABSTRACT

This article explores the efficiency of using the ETRO-02 ozonator, powered by solar energy, in the water purification process. The objective of the study is to find an environmentally friendly and economically efficient method for eliminating microorganisms in water by powering the ozonator with alternative energy sources. The research materials included water sourced from the Kapshagay reservoir, as well as solar panels and the ozonator device. During the study, solar panels with the capacity to produce 4.2 to 5.5 kWh of energy daily were used, which was sufficient to ensure the continuous operation of the ozonator. The total bacterial contamination in the water decreased from 12,000 CFU/ml to 45 CFU/ml, and coliform bacteria were reduced from 25 CFU/100 ml to 1 CFU/100 ml. Additionally, dangerous microorganisms such as Enterococcus, Salmonella, and Legionella were completely eliminated. The efficiency of the ozonator in removing bacteria and viruses was between 90-99%. In conclusion, the solar-powered ozonator proved to be an environmentally friendly and economically viable solution for effective water purification, particularly suitable for remote and rural areas.

KEYWORDS

Ozonator, water purification, solar energy, alternative energy, power supply system, photovoltaic cells, energy efficiency, renewable energy integration.

1. INTRODUCTION

Relevance of the scientific research work. Water scarcity is one of the pressing issues in the world today (Apolinário and Castro, 2024; García-Gil et al., 2021). Effective and sustainable methods for water purification are needed to address this problem (Novas et al., 2021). The use of ozonators is particularly important in the water disinfection process, as ozone is one of the strongest oxidants used in water purification (Abdykadyrov et al., 2023). Solar-powered ozonators operate with clean energy that does not harm the environment (Hafeez et al., 2021; Hendrickson et al., 2020). This method aligns with the UN's Sustainable Development Goals, particularly Goal 6 – "Clean Water and Sanitation".

Role of the ozonator. The efficiency and advantages of ozonators in water purification, combined with solar energy, enhance the sustainability of the water treatment system. To increase the efficiency of ozonators using solar energy, new technologies need to be implemented. For example, solar-powered desalination systems can reduce water production costs by up to 33% (Apolinário and Castro, 2024; Reif and Alhalabi, 2015). Additionally, ozonators are highly suitable for purifying water in areas lacking solar energy (Novas et al., 2021; Beltrán Novillo and Rey Barroso, 2017).

Potential of solar energy. Solar energy plays a significant role in water purification as an environmentally friendly and renewable resource. The use of solar energy reduces the emission of harmful gases and decreases dependency on fossil fuels (Shahsavari and Akbari, 2018). The compatibility of solar panels and ozonators enhances efficiency in water purification (Camera-Roda et al., 2019). According to studies, photovoltaic systems can be used to save electricity in water treatment technologies (da Costa and da Silva, 2021). The development of solar energy technologies increases the efficiency of these systems (Chu and Meisen, 2011; Gorjian, and Ghobadian, 2015).

Research objective. This study aims to investigate the effectiveness of systems that power ozonators with solar energy in water purification. Solar-powered ozonators will enable efficient and environmentally friendly water purification in the future. Research has shown that these systems can help reduce costs and improve water quality in purification processes (Apolinário and Castro, 2024; Dorevitch et al., 2020; Mecha and Chollom, 2020). Solar-powered systems may be effective in remote areas, and utilizing renewable energy sources ensures the efficient management of water resources (Kharraz et al., 2017; Thanigaivel et al., 2022).

Overall, the scientific research was conducted at the "Drilling Training" site of the Kazakh National Research Technical University named after K.I. Satpayev. At the training drilling site, drinking water is sourced from the Kapshagay reservoir. Based on an innovative technology powered by a solar system designed for 500 students, a pilot ETRO - 02 ozonator unit was developed, with a capacity of 5 kW (Abdykadyrov et al., 2021; Udhayakumar et al., 2016). The unit can disinfect and purify 8 m^3 of water per hour. The research work was conducted between 2020 and 2024 at the scientific laboratory of the Department of Electrical Engineering and Electronics.

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2. Materials and Methods

Research on the solar energy-powered ozonator system has attracted significant interest in recent years for water purification processes (Potivejkul et al., 1998; Abdikadyrov, A., Kalandarov, P., 2024). Numerous studies have demonstrated the effectiveness of using solar energy instead of traditional electricity for ozonators. For instance, connecting solar panels to ozonators can achieve energy efficiency while reducing the carbon footprint. Various studies have shown that solar energy and ozonators are effective in eliminating bacteria and viruses in water. As a result, sustainable water purification systems independent of natural resources are being developed (Draginsky et al., 2007; Abdykadyrov et al., 2023; Abdykadyrov et al., 2021).

However, these studies still have some limitations. For example, the stability of solar energy and the issues related to storage systems are major obstacles since ozonators cannot operate at night or when sunlight is minimal. Additionally, the efficiency of some systems may still be low. Researchers have also faced challenges in scaling the system for use in large water treatment plants (Jbilou et al., 2022; Nehari et al.,2019).

Regarding scientific advancements, there have been achievements in optimizing ozone generation processes and developing hybrid systems (e.g., incorporating wind or other energy sources). These solutions enhance the independence and efficiency of the system. Nevertheless, reducing energy costs and fully automating the process still require further research (Vezzu et al., 2009; Palej P. et al., 2019; Tikhomirov et al., 2020; Da Silva et al., 2009).

2.1 Scientific Research Object

Currently, powering ozonators with alternative solar energy in the surface water purification process is a pressing issue due to the high cost of ozone technology (Da Silva et al., 2009). This has led to the necessity of supplying it with alternative energy sources. The ozonator purifies water and eliminates pollutants (Abdykadyrov et al., 2023; Abdykadyrov et al., 2023), while solar panels provide the required energy. However, several problems have been identified in this system:

Firstly, the efficiency of solar panels is weather-dependent; for example, on sunny days, a 1 m^2 panel can generate 150 - 200 W of energy, while on cloudy days, this figure can drop by up to 50%. This may result in insufficient energy to effectively purify water if the ozonator's average power consumption is between 50-100 W;

Secondly, inverters are used to convert the energy obtained from the sun from direct current to alternating current, but their efficiency varies between 85 - 95%. These losses reduce the overall energy efficiency of the system;

Thirdly, the capacity of the energy storage system is also limited. For instance, batteries can cover energy needs for up to 10 - 12 hours at night or on cloudy days, but a prolonged lack of sunlight may jeopardize the system's stability.

Similarly, the climatic conditions of the research area play an important role, as the efficiency of the system may decrease in regions with low solar radiation, leading to interruptions in water purification processes. The overall scientific research object is presented in Table 1 below (Kim et al., 2008).

Table 1: Key Research Objects in the Study of Powering an Ozonator with Solar Energy for Water Purification

Research Objects	Description
Ozonator	A device that generates ozone (O_3) used in water purification systems to remove contaminants.
Solar energy system	A system of solar panels and inverters that powers the ozonator using alternative energy sources.
Water purification process	The method of purifying water by using an ozonator to eliminate contaminants and bacteria.
Photovoltaic solar panels	Devices that convert sunlight into electricity, crucial for continuous operation of the ozonator.
Inverter	A device that converts the direct current (DC) from the solar panels into alternating current (AC) to power the ozonator.
Energy storage system (batteries)	Stores the energy collected from the sun and powers the ozonator during cloudy days or at night.
Water source to be purified	The source of water to be treated by the ozonator (e.g., river water, industrial wastewater, etc.).
Climatic conditions of the research area	Sunlight intensity and weather conditions that impact the effectiveness of solar energy utilization.
Energy efficiency	Assessment of overall energy consumption and efficiency of powering the ozonator with solar energy.

This Table 1 describes the main elements of the solar energy-powered ozonator system, including the role of the ozonator in water purification and the electricity production of the solar panels. The inverter is necessary to convert the direct current obtained from the solar panels into alternating current to power the ozonator, while the energy storage system ensures the continuous operation of the system when there is no sunlight. Climatic conditions and energy efficiency are important factors that affect the stability of solar energy utilization.

2.2 Scientific Research Methods

During the research of the solar energy-powered ozonator system in the water purification process, several issues were identified. Firstly, it was challenging to continuously monitor the ozonator's performance in real-time, as the ozone concentration should be maintained between 0.1 - 0.3 ppm, while fluctuating sunlight conditions hinder the ability to keep this parameter stable. Secondly, since the efficiency of solar panels is directly related to the intensity of sunlight, the amount of energy produced on cloudy or dark days may drop below 150 - 200 W, potentially failing to meet the ozonator's power requirements. Thirdly, although the ozonator's power consumption is consistently between 50 - 100 W, a constant shortage of energy may disrupt the water purification process. Additionally, the concentration of pollutants in the water may not always decrease to the required levels, which could adversely affect the purification efficiency. Lastly, a deficit in energy utilization from renewable sources could reduce the economic viability of the system. To address such issues, the following research methods can be employed (Figure 1) (Dong et al., 2013; Udhayakumar et al., 2016)

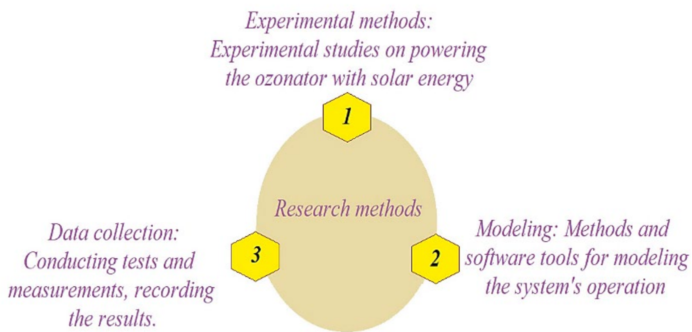


Figure 1: Methods of Research for Solar-Powered Ozonator

This Figure 1 illustrates three different research methods for studying the solar energy-powered ozonator system. The first method is experimental, where the operation of the ozonator using solar energy is verified through practical experiments. This method is crucial for obtaining accurate results, as it allows for the assessment of the actual functioning of the system under investigation. The second method is modeling, which involves using specialized software and models to predict the system's performance. This method helps evaluate the system's efficiency in the future without conducting experiments. The third method is data collection, which includes recording measurements and results. This phase allows for the refinement of information obtained from experimental and modeling methods, enhancing the accuracy of the research. In this study, we place particular emphasis on the first two methods.

The research of solar energy-powered ozonator systems in the water purification process focuses on environmentally sustainable methods of treating water, where efficient energy use is crucial. In a similar way, assessing the quality of masking noise interference generated by spatial noise generators contributes to enhancing the performance of such systems by minimizing signal disruptions in control mechanisms, ensuring more reliable purification processes (Smailov et al., 2021; Smailov et al., 2020).

2.3 Theory of Powering the Ozonator with Solar Energy

The process of powering the ozonator with solar energy involves converting sunlight into electrical energy, which is then used to meet the needs of devices designed for ozone production. This process consists of several key stages (Figure 2):

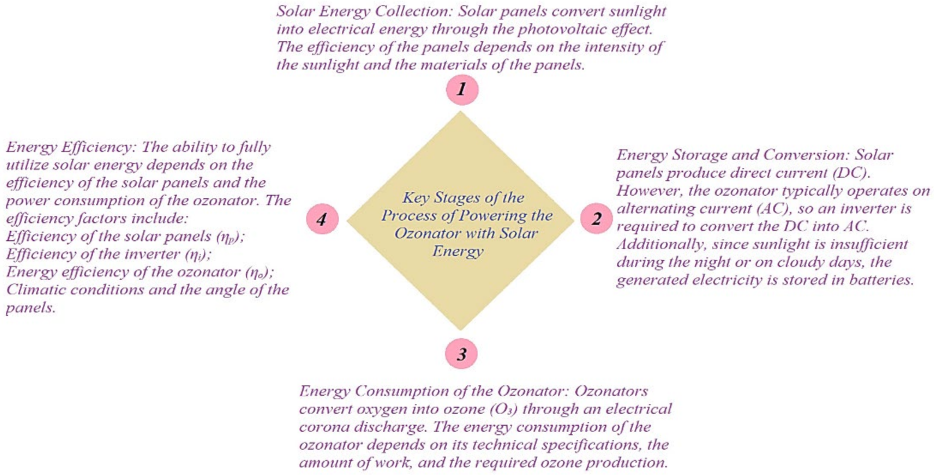


Figure 2: Key Stages of Solar-Powered Ozonator Operation

The second image illustrates the four main stages of the process of powering the ozonator with solar energy. In the first stage, sunlight is converted into electrical energy through the photovoltaic effect. Then, direct current is converted into alternating current, and energy is stored. In the final stages, the energy consumption characteristics of the ozonator and the overall system efficiency are analyzed. Now, taking these factors into account, let us develop the mathematical model of the system. To develop a mathematical model of powering the ozonator with solar energy, it is necessary to consider key factors such as: Solar panel power P_{solar}, Battery charge level $E_{battery}$, Ozonator energy consumption $P_{ozonator}$, Solar irradiance I_{solar}, System losses (efficiency factor).

The model consists of three main components: energy generation from the solar panel, energy storage in the battery, and energy consumption by the ozonator.

Solar Panel Power. The power generated by the solar panel can be expressed as:

$$P_{solar}(t) = I_{solar}(t) \cdot A \cdot \eta_{panel} \quad (1)$$

where: $I_{solar}(t)$ is the solar irradiance over time (W/m^2), A is the area of the panel (m^2), η_{panel} is the efficiency of the solar panel.

Battery Charge Level. The energy stored in the battery, $E_{battery}(t)$, can be described by the following differential equation:

$$\frac{dE_{\text{battery}}(t)}{dt} = P_{solar}(t) - P_{ozonator}(\text{t}) \cdot \eta_{conv} \quad (2)$$

where: $P_{solar}(t)$ is the power generated by the solar panel, $P_{ozonator}(t)$ is the energy consumed by the ozonator, η_{conv} is the conversion efficiency.

Ozonator Energy Consumption. The energy consumption of the ozonator can be either constant or time-dependent. If it is constant, we define it as:

$$P_{ozonator}(\text{t}) = P_{ozonator.const} \quad (3)$$

System Dynamics. If the energy generated by the solar panel is insufficient to meet the ozonator's needs, the system will use energy stored in the battery:

$$E_{battery}(t) \geq E_{min} \quad (4)$$

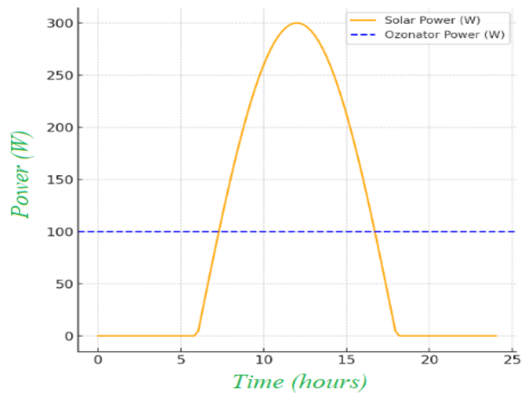
where E_{min} is the minimum battery charge level.

Final Model Equations:

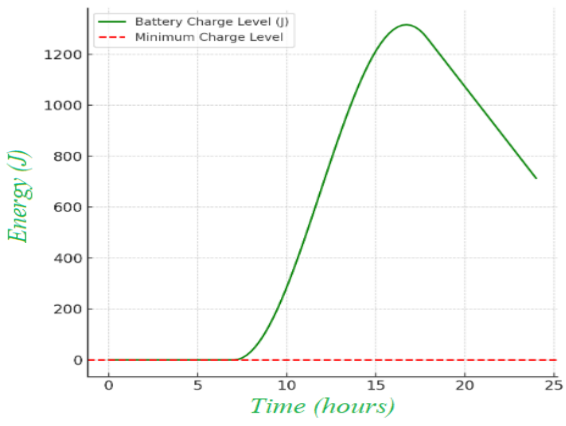
- Solar power generated: $P_{solar}(t) = I_{solar}(t) \cdot A \cdot \eta_{panel}$;
- Battery charge level: $\frac{dE_{\text{battery}}(t)}{dt} = P_{solar}(t) - P_{ozonator}(\text{t}) \cdot \eta_{conv}$;
- Ozonator power consumption: $P_{ozonator}(\text{t}) = P_{ozonator.const.}$

This model describes the process of powering the ozonator with solar energy by accounting for the balance between solar panel power and the ozonator's energy requirements.

Based on this theoretical information, let's plot the solar energy and ozonator power consumption (a) and the battery charge level over time (b) using Python (Figure 3).



a) Solar Power Generated and Ozonator Power Consumption



b) Battery Charge Level Over Time

Figure 3: Operational Dynamics of a Solar-Powered Ozonator System

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The graph showing solar energy and ozonator power consumption clearly illustrates that throughout the day, the solar energy generation (orange curve) reaches its maximum level, effectively meeting the ozonator's constant power consumption (blue line). In contrast, the graph depicting the battery charge level over time indicates that the energy level in the battery increases due to the advantages of solar energy during the day, but it decreases in response to the ozonator's power consumption. The battery charge never drops below the minimum level, ensuring the reliability of the system and supporting the continuous operation of the ozonator. Thus, the graphs depict the dynamics of the solar-powered ozonator system and characterize the efficiency of its energy balance.

3. Results and Discussions

The scientific research was conducted at the "Drilling Training" site of the Kazakh National Research Technical University named after K.I. Satbayev, located in the city of Konaev. During the summer months, approximately 500 students undergo practical training at the site for 2-3 months. Unfortunately, there is a shortage of drinking water at the site, so surface water from the Kapshagay reservoir is used for household purposes and food preparation in the kitchen. However, during these 3 months, several students suffered from various illnesses due to the water quality. To address this issue, we decided to develop a pilot ETRO-02 ozonator unit based on innovative technology, utilizing electrical corona discharge. The unit is designed to disinfect and purify up to 8 m^3 of water per hour. Since there is no centralized power supply system at the site, we opted to use solar energy. The primary objective of the scientific research is to study the ETRO-02 ozonator system powered by solar energy for use in the water purification process. The energy flow diagram for the solar-powered ozonator system is presented in Figure 4.

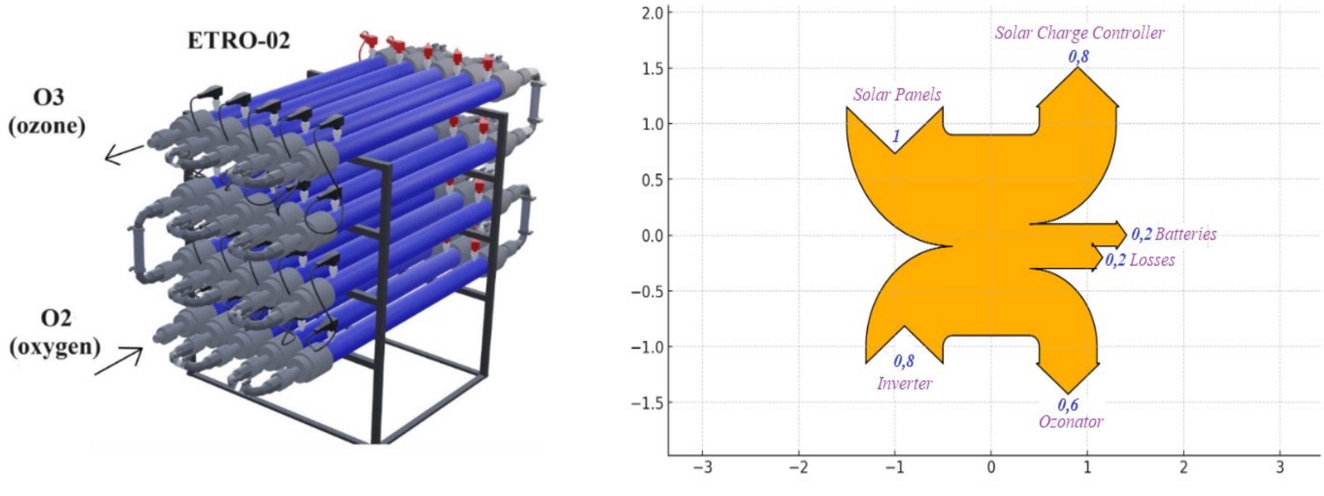
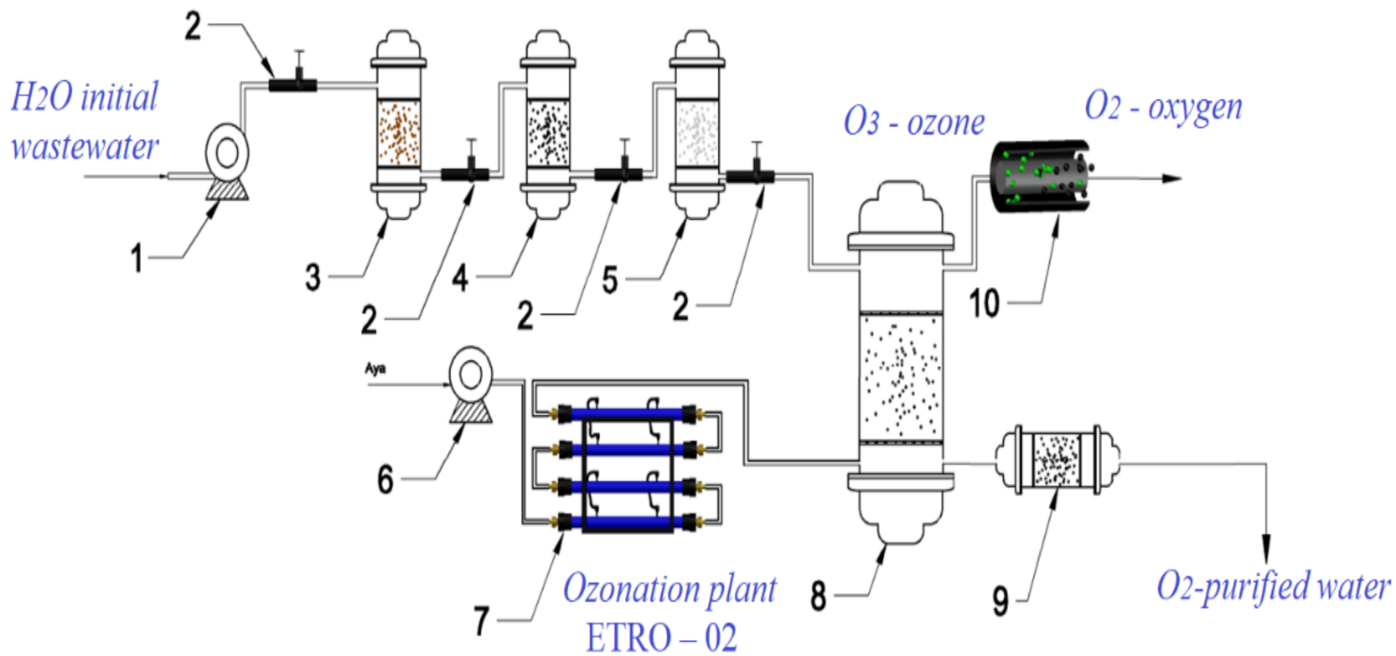


Figure 4: Energy Flow Diagram for the Solar-Powered ETRO-02 Ozonator

The diagram presented in Figure 4 illustrates the energy flow within the system that powers the ozonator using solar energy. Initially, the solar panels generate 1 unit of energy. Of this energy, 0.2 units are lost while passing through the Solar Charge Controller, and 0.8 units of energy are transferred to the batteries and inverter. In the batteries, 0.2 units of energy are stored, while 0.2 units are lost in the process. The inverter converts 0.8 units of energy and delivers 0.6 units to the ozonator. As a result, part of the energy is lost, and the remaining energy is used to power the ozonator.

The technological scheme of the surface water ozonation and filtration system using the ETRO-02 ozonator is presented in Figure 5.



Here: 1 - pump, capacity 10m^3; 2 - valve, d = 36x40 mm; 3 - sand filter made of zeolite; 4 - activated carbon filter; 5 - sand filter made of quartz; 6 - air compressor; 7 - ozonator based on electrical corona discharge; 8 - tank (H_2O+O_3); 9 - membrane filter; 10 - ozone destructor

Figure 5: Wastewater Treatment System Using Ozonation and Filtration Technology

When the initial water sample was analyzed in a specialized laboratory, its chemical composition met the standards of GOST 2874-82. However, microbiological analysis revealed the presence of harmful microorganisms that are dangerous to human health. During the 30-minute disinfection process (with an ozone concentration of 1 - 3 mg/L), the harmful microorganisms in the water were completely reduced to levels that meet the requirements set by the Maximum Permissible Concentrations (MPC). These research results can be seen in Table 2 below.

Table 2: Microorganisms in Initial Surface Water of the Reservoir and Their Maximum Permissible Concentrations (MPC)

Type of Microorganism	MPC (Maximum Permissible Concentration)	Initial number of microorganisms in water before ozonation	Initial number of microorganisms in water after ozonation	Explanation
Total bacterial contamination	≤ 1000 CFU/ml	12000	45	General bacterial indicator, showing the degree of water contamination.
Coliform bacteria	≤ 3 CFU/100 ml	25	1	Bacteria originating from intestinal flora, an indicator of fecal pollution.
Enterococcus (fecal streptococcus)	≤ 1 CFU/100 ml	37	Not detected in water	Enterococcus bacteria spread through fecal contamination.
Salmonella	0 CFU/1 liter	12	Not detected in water	Dangerous pathogenic bacteria that cause infectious diseases.
Legionella	0 CFU/1 liter	145	Not detected in water	Bacteria causing respiratory diseases, such as Legionnaires' disease.
Pathogenic viruses	0 CFU/10 liters	97	Not detected in water	Waterborne viruses that can cause health-threatening infections.
Protozoa (Amoeba, Giardia)	0 CFU/50 liters	65	Not detected in water	Waterborne parasites causing severe gastrointestinal diseases.

From Table 2, it can be observed that the ozonation process reduced the total bacterial contamination in the water from 12,000 CFU/ml to 45 CFU/ml, a decrease of 99.6%. Coliform bacteria were reduced from 25 CFU/100 ml to 1 CFU/100 ml, showing a 96% decrease, and Enterococcus, initially at 37 CFU/100 ml, was completely eliminated from the water. Salmonella and Legionella were also not detected in the water after ozonation, indicating their complete eradication. This demonstrates the high effectiveness of the ozonator in purifying water from pathogenic microorganisms.

3.1 Ozonator Performance and Water Purification Efficiency

The performance of the ozonator is determined by its ozone production rate and concentration, which are key factors in the water purification process. Table 3 below presents the indicators of the ozonator's performance and water purification efficiency.

Table 3: Ozonator Performance and Water Purification Efficiency Indicators

Parameter	Performance Value/Efficiency Indicator	Explanation
Ozone production rate	5-50 g/h (depending on the type of ozonator)	The ozone production rate is a key factor in water purification.
Ozone concentration	1-3 mg/L (in water)	The concentration of ozone directly affects purification efficiency.
Ozone solubility in water	Approximately 570 mg/L (at 20°C)	Ozone's solubility in water ensures its reaction with contaminants during the purification process.
Water purification efficiency	90-99% (for eliminating bacteria and viruses)	The ozonator system effectively removes harmful microorganisms and chemical contaminants from water.

Table 2 presents the key parameters of the ozonator's performance and water purification efficiency. The ozone production rate and concentration play an important role in water purification, while the solubility of ozone in water ensures the effectiveness of the purification process. Additionally, it was observed that the ozonator has the capability to eliminate 90-99% of bacteria and viruses in the water.

3.2 Energy Production Indicators of Solar Panels

The energy production indicators of the solar panels used to power the ETRO-02 ozonator are crucial in determining the system's efficiency during the water purification process. The amount of energy produced daily varies between 4.2 and 5.5 kWh, which is sufficient to ensure the continuous operation of the ozonator. These fluctuations in energy production highlight the importance of optimizing the placement of solar panels and implementing energy storage solutions, especially during days of lower energy production. Overall, the research results confirm that the solar energy system is adequate for powering the ozonator and can be used as a sustainable solution for water purification. The amount of energy produced daily by the panels (kWh) is provided in Table 4 below, which reflects the results of the study conducted over a 7-day period.

Table 4: Daily Solar Energy Production for Ozonator System

Daily research	1 day	2 day	3 day	4 day	5 day	6 day	7 day
Power, kWh	4,2	4,8	5,1	5,0	4,7	5,2	5,5

Table 4 shows the amount of energy produced daily by the solar panels (kWh). On the first day, 4.2 kWh of energy was generated, while on the seventh day, this amount increased to 5.5 kWh, which is the highest recorded output. The lowest production occurred on the first day, but the overall energy output steadily increased each day. These data demonstrate the efficiency of the solar panels and their ability to provide a stable power supply to the ozonator system. Now, let's graphically represent the data from Table 4 (see Figure 6).

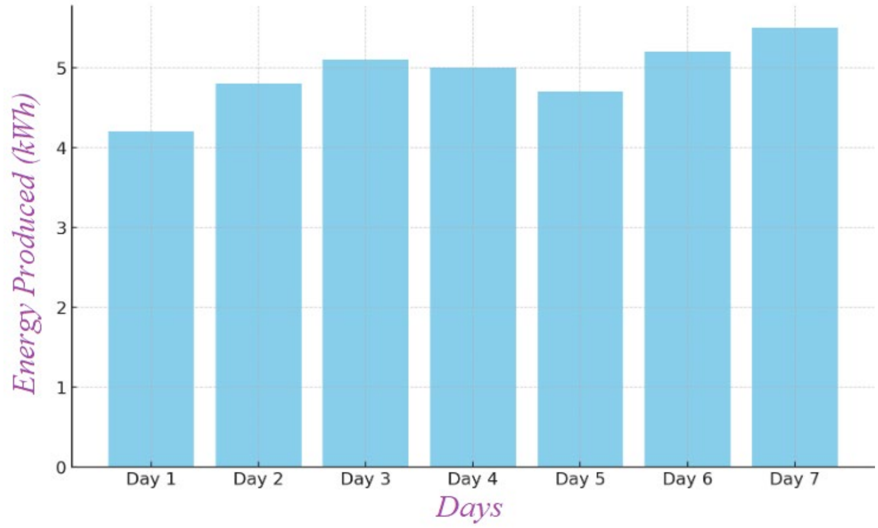
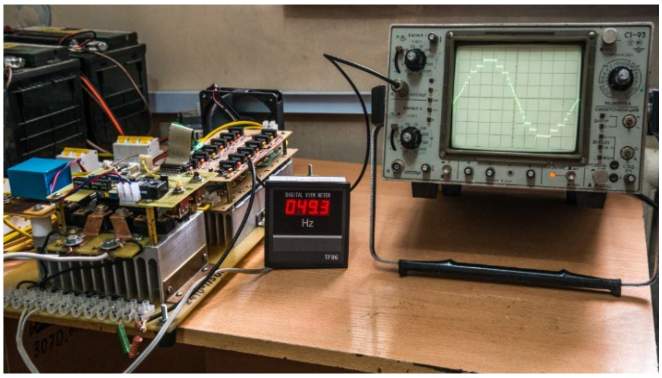


Figure 6: Daily Energy Production from Solar Panels

This diagram illustrates the daily energy production (kWh) of the solar panels. On the first day, 4.2 kWh of energy was generated, and by the seventh day, the energy output reached its peak at 5.5 kWh. On the fourth day, 5.0 kWh was produced, indicating the stability of energy generation and consistently high energy output throughout the week.

The electrical schematic for the practical application of powering the innovative ETRO-02 ozonator unit with a solar energy system is presented in Figure 7 below.



a) Oscilloscope for measuring electric current and the electrical control unit of the ozonator

b) ETRO-02 ozonator unit

c) System for powering the ozonator with alternative energy through solar panels

Figure 7: Practical image of the ETRO-02 pilot ozonator powered by solar energy, based on electrical corona discharge

This figure presents the general view of the ETRO-02 ozonator system powered by alternative solar energy. In image (a), an oscilloscope for measuring high-frequency electric current and the electrical control unit of the ozonator are shown under laboratory conditions. In image (b), the assembled version of the ozonator unit designed for industrial testing is depicted. Image (c) illustrates the practical use of the ozonator powered by solar panels, highlighting the system's energy efficiency and its environmentally friendly solution.

3.3 The Effect of Solar Energy on the Efficiency of the Ozonator's Operation

Let us conduct a mathematical modeling of the effect of solar energy on the efficiency of the ozonator's operation. For this, it is necessary to take into account the energy balance and the overall characteristics of the system. The model will focus on the delivery of solar energy to the ozonator, energy storage, and its impact on efficiency (Taissariyeva and Seidaliyeva, 2017;

Taissariyeva, and Seidaliyeva, 2017).

Solar Energy Production:

$$E_{solar} = A_{panel} \cdot I_{solar} \cdot \eta_{panel} \cdot t_{sunlight} \quad (5)$$

where, E_{solar} - energy produced by solar panels (kWh), A_{panel} - area of the solar panels (m^2), I_{solar} - solar irradiance (kW/m^2), η_{panel} - efficiency of the solar panels (%), $t_{sunlight}$ - duration of sunlight (hours).

Energy Storage Losses:

$$E_{stored} = E_{solar} \cdot \eta_{storage} \quad (6)$$

where, E_{stored} - energy stored in the batteries (kWh), $\eta_{storage}$ - efficiency of the storage system (%).

Energy Consumption by the Ozonator:

$$E_{\mathrm{ozonator}} = P_{\mathrm{ozonator}} \cdot t_{\mathrm{operation}} \quad (7)$$

where, $E_{ozonator}$ - energy required by the ozonator (kWh), $P_{ozonator}$ - power of the ozonator (kW), $t_{operation}$ - operation time of the ozonator (hours).

Ozonator Efficiency:

$$\eta_{ozonator} = \frac{E_{\mathrm{ozonator}}}{E_{stored}} \quad (8)$$

where, ηozonator - efficiency of the ozonator powered by solar energy (%), $E_{ozonator}$ - energy consumed by the ozonator (kWh), Estored - stored energy in the system (kWh) (Taissariyeva and Issembergenov, 2014).

These expressions (5), (6), (7), and (8) allow us to calculate how efficiently the energy produced by solar panels is delivered to the operation of the ozonator. The system depends on the efficiency of the solar panels, the energy storage losses, and the energy consumption of the ozonator.

3.4 Analysis of the Scientific Research

The research results demonstrated that the ETRO-02 pilot ozonator system, powered by solar energy, is an environmentally friendly method for effective water purification (Abdykadyrov et al., 2024). By using the ozonator, 90-99% of bacteria and viruses were eliminated, ensuring high efficiency in removing harmful microorganisms from the water (see Figure 8).

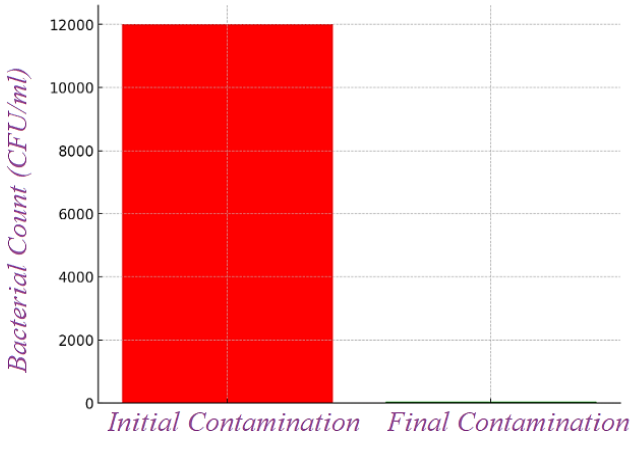


Figure 8: Bacterial Contamination Before and After Ozonation

This diagram shows the bacterial contamination levels in the water before and after using the ozonator. The initial contamination level was significantly high, around 12,000 CFU/ml. After the ozonator was used, the bacterial contamination level decreased to near-zero values, demonstrating the effectiveness of the water purification process. This result confirms the ozonator's high capability in completely eliminating bacteria.

The solar panels provided a continuous power supply to the ozonator, enabling round-the-clock water purification (Abdykadyrov et al., 2024). However, the system's efficiency depended on the consistency of sunlight (see Figure 9). The energy storage systems allowed for power to be stored and used during the night, but extended periods without sunlight could affect the system's stability. Overall, the solar-powered ozonator system proves to be a sustainable and accessible solution for water purification, particularly suitable for remote areas.

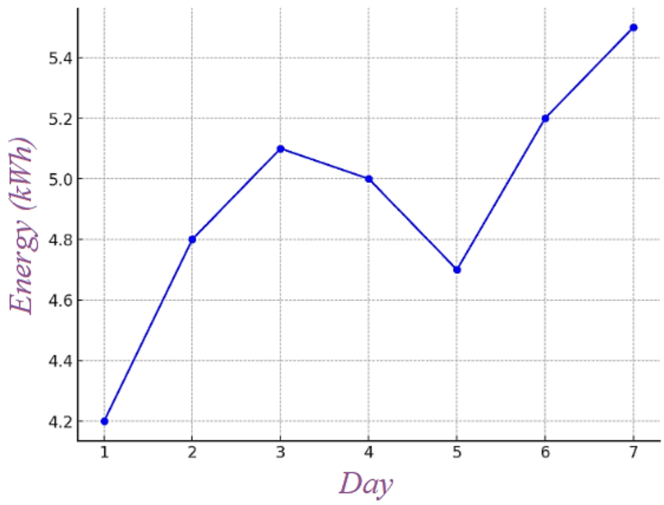


Figure 9. Daily Energy Production from Solar Panels (kWh)

This diagram illustrates the amount of energy produced daily by the solar panels throughout the week (in kWh). On the first day, 4.2 kWh of energy was generated, while by the third day, energy production reached its highest point at 5.0 kWh. On the fifth day, production decreased to approximately 4.6 kWh, but by the seventh day, it rose again to 5.4 kWh. Despite some fluctuations in daily energy output, the overall trend shows an increase in energy production.

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4. Conclusion

This scientific research focused on investigating the efficiency of the ETRO-02 ozonator system powered by solar energy for water purification. The solar-powered ozonator system offers an environmentally friendly and sustainable solution for water disinfection.

The research results demonstrated that the ozonator can effectively eliminate 90-99% of bacteria and viruses. Specifically, the system was able to reduce total bacterial contamination from 12,000 CFU/ml to 45 CFU/ml, while coliform bacteria decreased from 25 CFU/100 ml to 1 CFU/100 ml. The high efficiency of the ozonator is attributed to its consistent ozone production and capability to eliminate microorganisms in water. During the study, it was found that the solar panels produced between 4.2 and 5.5 kWh of energy per day, sufficient for the continuous operation of the ozonator. The system efficiently harnessed solar energy during the day and ensured uninterrupted operation through energy storage systems at night. Furthermore, the results indicate that using solar energy enhances the economic efficiency of the water purification process.

The ETRO-02 ozonator has proven to be an affordable and effective solution for addressing water purification issues, particularly in rural and remote areas. The ecological and economic advantages of the solar-powered system support its long-term use, making this technology a key player in future water resource management.

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