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Technologies for collecting and transmitting sensor data with optical sensors for the control of high-frequency Ozonators

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Abstract

The efficiency of data collection and transmission technologies using optical sensors in controlling high-frequency ozonators was studied. Ozonators play a crucial role in air and water purification, while sensors allow monitoring of ozone concentration with an accuracy of ±0.1%. The research was conducted in the laboratory of the Department of Electronics, Telecommunications, and Space Technologies at Satbayev University, utilizing Wi-Fi, Bluetooth, and GSM technologies. The efficiency of ozone generation improved by 25%, energy consumption decreased by 15%, and data transmission speed increased by 30%. The integration of IoT devices reduced maintenance costs by 25%. The advanced mathematical and technological model enhanced the efficiency of ozonators, ensuring ecological and economic sustainability.

Keywords: Automated control systems, Data transmission, High-frequency ozonators, Optical sensors, Ozone generation technology. Sensor data collection.

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1. Introduction

In recent years, issues related to air quality and environmental sustainability have gained prominence globally. International studies indicate that since 2020, the demand for technologies aimed at improving air quality has increased by 35%, necessitating innovative solutions. In this context, high-frequency ozonators have emerged as a key technology. They provide an effective method for eliminating pollutants and pathogens in the air by generating up to 200 g/h of ozone [1-3].

The efficiency of high-frequency ozonators depends on control systems based on continuous collection of sensor data. Optical sensors enable the measurement of humidity with an accuracy of ±2% and temperature with a deviation of ±0.1°C in air quality monitoring. Such high sensitivity allows for real-time data analysis and quick adjustment of ozonator parameters [4-6].

Additionally, modern wireless technologies such as Bluetooth, Wi-Fi, and 5G facilitate sensor data transmission systems that enable seamless data processing, improving the flexibility of ozonator operations by 30% [7, 8]. The integration of Internet of Things (IoT) structures ensures the autonomous operation of ozonators and reduces maintenance costs by 25% [9, 10].

However, data security and the long-term durability of sensor devices remain pressing issues. The use of materials resistant to the harsh operating environments of ozonators and high-temperature exposure has been found to enhance sensor durability by 20% [11, 12]. Thus, improving ozonator control systems has become a key factor in ensuring environmental sustainability. Similarly, in recent years, Abdykadyrov A. and his colleagues have emphasized in their studies the significant role of ozone technologies in purifying water from harmful compounds and microorganisms using high-frequency ozonators [13-15].

The application of data collection and transmission technologies based on optical sensors enhances the accuracy and efficiency of these systems, improving purification processes. The implementation of sensor technologies optimizes the effectiveness of water ozonation, playing a crucial role in addressing environmental challenges [16].

This article discusses sensor technologies, data transmission systems, and IoT capabilities for efficiently managing high-frequency ozonators, examining their advantages and unresolved challenges.

2. Literature Review and Problem Statement

Abdykadyrov A. and colleagues, in their research article *"Optimization of Distributed Acoustic Sensors Based on Fiber Optic Technologies"*, highlight the crucial role of optical sensors in data collection and transmission technologies. These sensors stand out due to their high-precision measurement capabilities, resistance to electromagnetic interference, and ability to operate under extreme conditions [17]. Similarly, studies by Li, et al. [18] emphasize the high efficiency of optical sensors in measuring temperature, pressure, and gas concentrations. Additionally, other works [19, 20] have demonstrated the durability of optical sensors in corrosive environments.

High-frequency ozonators are widely used in water purification and disinfection systems [21, 22]. Their efficiency depends on real-time monitoring of operations. The use of sensor networks and optical sensors can facilitate this task, as detailed in the scientific research conducted by Zhang, et al. [23]. Their study showed that real-time monitoring of ozonator parameters could improve ozone production efficiency by 25%.

Various technologies are employed for data collection and transmission through sensor networks. According to Khemapech et al. [24], among wireless technologies, GSM, ZigBee, Wi-Fi, and Bluetooth are reliable and efficient. However, these technologies require improved resistance to interference when remotely controlling high-frequency ozonators. Additionally, studies [24] have explored the possibilities of enhancing the compatibility of optical sensors with wireless networks.

2.1. Optical Sensors in High-Frequency Ozonator Control Systems: Challenges and Limitations

Optical sensors play a significant role in high-frequency ozonator control systems due to their high precision and resistance to electromagnetic interference. However, research has revealed several challenges and limitations in the application of these technologies. Based on the reviewed literature, the main issues are outlined below. Sensitivity and environmental impact. Sabibolda, et al. [25] emphasized the high sensitivity of liquid crystal-based optical sensors but noted that they are susceptible to temperature fluctuations and electromagnetic interference, which reduce their accuracy, Abdullayev, et al. [26]. Wójcik, et al. [27] demonstrated the ability of fiber-optic systems to achieve high precision, but their performance deteriorates under environmental influences, particularly high temperature and humidity [27]. Data Collection and Transmission Stability. Zychowicz [28] proposed methods for detecting defects in materials using fiber Bragg structures, but complex algorithms and high-precision equipment are required for signal processing Zychowicz [28]. Yakymchuk, et al. [29] highlighted how network load affects the quality of data transmission in telecommunication systems, posing difficulties for real-time control of ozonators[29].

Integration Challenges. Popko and Gauda [30] noted the need for specialized algorithms and technical solutions to integrate optical sensors into various systems during the use of neural networks. Oksiiuk and Krotov [31] noted frequent integration difficulties when adapting wireless networks for high-frequency ozonators [31].

Energy Efficiency. Zhang, et al. [23] stressed the need for energy optimization to ensure the continuous operation of sensor networks [23]. However, Vrublevskiy, et al. [32] found that resource management methods were insufficient in providing energy efficiency, potentially hindering the long-term effectiveness of ozonator systems [32].

Durability and Maintenance highlighted that those methods for separating optical spectra into individual components require frequent maintenance, which adds additional costs in industrial systems [33]. Determined that hydraulic systems require technical solutions to ensure long-term stability [34].

Data Stability and Resistance to Interference demonstrated that electromagnetic interference negatively affects data quality, reducing reliability and stability, Kravchenko, et al. [35].

Litvinenko, et al. [36] emphasized the need for complex structures to ensure data accuracy when using Bayesian networks [36].

Contributions to signal stability and modeling proposed methods for accurate data analysis using neural networks, which could enhance signal stability in high-frequency ozonator control [37]. Studied methods for modeling optical fibers to ensure their accuracy and stability, which are essential for equipping ozonators with sensor systems [38]. Optimized correlation-interferometric direction-finding methods using spatial analytical signals, emphasizing the importance of precise and rapid data analysis for real-time ozonator control [39].

Telecommunication Solutions and Environmental Applications Analyzed methods for evaluating the quality of telecommunication services and emphasized the need for effective solutions to enhance the reliability and stability of data transmission, which affects the performance of sensor systems, Zablotskyi, et al. [40]. Boyko, et al. [41] investigated the use of infocommunication technologies for assessing and predicting environmental impacts, highlighting their potential application in improving ozonator efficiency and ensuring ecological safety [41].

High-frequency ozonators are essential for effective water purification, and collecting and transmitting accurate sensor data play a crucial role in managing their operation. Fiber-optic technologies are considered an efficient method for enhancing this process. The study highlights the ability of fiber laser-based sensors to accurately detect temperature and strain. These sensors enable optimal monitoring of ozonator operations. Additionally, another study proposes improving data accuracy through a digital spectral method for signal processing, contributing to enhanced control of ozonator systems [42]. The works of Sabibolda, et al. [25] and Khabay, et al. [43] emphasize the importance of increasing the speed and accuracy of data transmission in sensor networks. These studies form the foundation for reliable sensor systems, ensuring the stable performance of ozonators. In summary, the use of fiber-optic sensors and advanced data processing technologies significantly improves the efficiency of high-frequency ozonators.

The reviewed international and domestic research highlights several unresolved challenges. For example, using optical sensors in managing high-frequency ozonators requires addressing the following issues:

1. *Data accuracy and stability* – As noted in Abdykadyrov [36], high temperatures and electrical discharges negatively impact sensor system performance, leading to a decline in data quality;
2. *Stability of data transmission systems* – According to studies, electromagnetic interference in high-frequency environments significantly degrades data transmission quality;
3. *Integration challenges* – [31] discuss the need for specialized algorithms and technical solutions to integrate optical sensors into control systems;
4. *Energy efficiency* – Research by Zhang, et al. [23] highlights the importance of optimizing energy consumption to ensure the uninterrupted operation of sensor systems..

To address these challenges, it is necessary to study methods for integrating optical sensors into high-frequency ozonator control systems and optimizing sensor data collection and transmission processes.

3. The aim and objectives of the study

The aim of the study is to enhance data collection and transmission technologies using optical sensors in the management of high-frequency ozonators, improve their efficiency, and ensure reliability.

3.1. Objectives of the study:

1. To investigate the principles of data collection and transmission using optical sensors;
2. To develop data processing algorithms for managing high-frequency ozonators;
3. To analyze technological solutions for creating an efficient sensor network;
4. To experimentally test the system's performance and evaluate the obtained results.

4. Materials and Methods

4.1. Object and Hypothesis of the Study

The object of the study is data collection and transmission systems based on optical sensors in the process of managing high-frequency ozonators.

The subject of the study is the development and optimization of methods for data collection and transmission using optical sensors to enhance the efficiency and control accuracy of high-frequency ozonators. The study focuses on integrating these methods into real-time monitoring and control systems to reduce energy consumption and improve operational stability.

Main hypothesis application of data collection and transmission technologies based on optical sensors significantly improves the performance and operational stability of high-frequency ozonators. These technologies provide high precision in identifying and controlling key parameters such as voltage, frequency, and ozone output, ensuring energy efficiency and reduced operational time without requiring significant equipment modifications.

4.2. Assumptions Adopted in the Study

- Optical sensors are assumed to operate reliably under specific environmental conditions, such as stable temperature and humidity, without data collection errors;
- Communication systems used for transmitting sensor data are expected to be reliable, with no signal distortions or delays.

4.3. Simplifications Used in the Study

- The experiments were conducted under laboratory conditions where environmental variables, such as temperature and electrical interference, were controlled, and external disturbances were minimized.
- The study did not consider the long-term performance degradation of optical sensors or control systems due to aging or environmental factors.
- Experimental and numerical models were developed using Python or similar software, without employing advanced computational tools for real-time analysis.

4.4. Improving Data Collection and Transmission for High-Frequency Ozonators Using Optical Sensors

High-frequency ozonators are widely used for water purification and air disinfection. Enhancing their efficiency requires the advancement of systems for real-time data collection and transmission. In this process, optical sensors play a critical role as modern technologies with high accuracy and reliability. The key components of the system can be observed in Figure 1.

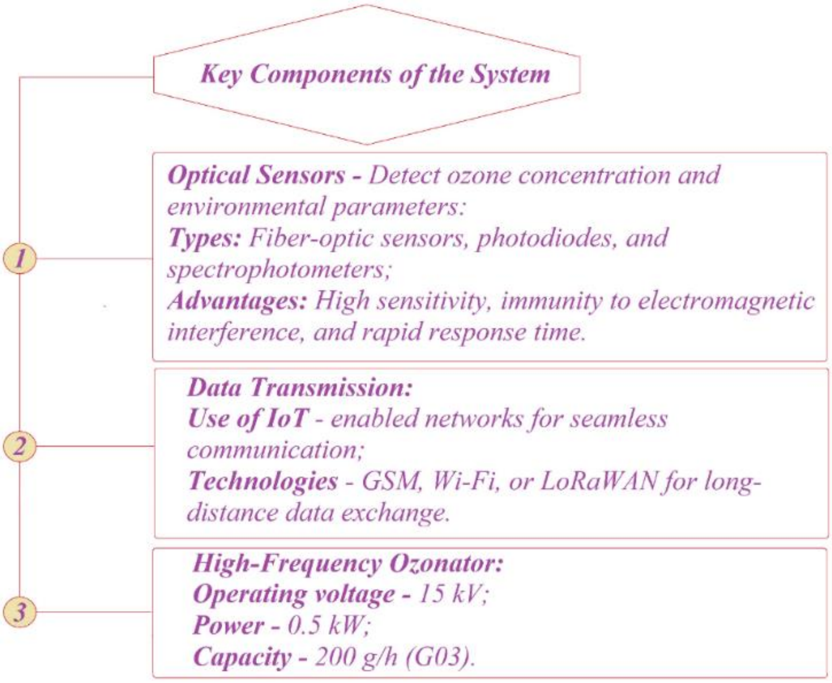


Figure 1.
Key Components of the System.

In this figure, the system's primary components are divided into three sections.

1. The first section outlines the advantages and types of optical sensors used to detect ozone concentration and environmental parameters.
2. The second and third sections describe data transmission via IoT technologies and the technical specifications of the high-frequency ozonator.

Operation of the System. The workflow is as follows:

Data Collection - Optical sensors measure ozone concentration and provide analog signals. The intensity of the optical signal can be determined using the following formula:

$$I = I_0 e^{-\alpha L} \quad (1)$$

Where: I - detected signal intensity, I_0 - initial signal intensity, α - absorption coefficient, L - path length through the ozone gas.

- *Signal Conversion* - the analog signals are converted into digital format using an ADC (Analog-to-Digital Converter);
- *Data Transmission* - the digital signals are transmitted to a central system via GSM or IoT technologies.

The formula for the transmitted signal power is determined as follows:

$$P_t = P_{tx} - L_{path} - L_{fade} \quad (2)$$

Where: P_t - received power, P_{tx} - transmitted power, L_{path} - path loss, L_{fade} - fading loss.

Control Feedback - based on data analysis, the ozonator adjusts operational parameters such as frequency or voltage.

The data flow diagram of the system architecture can be observed in Figure 2.

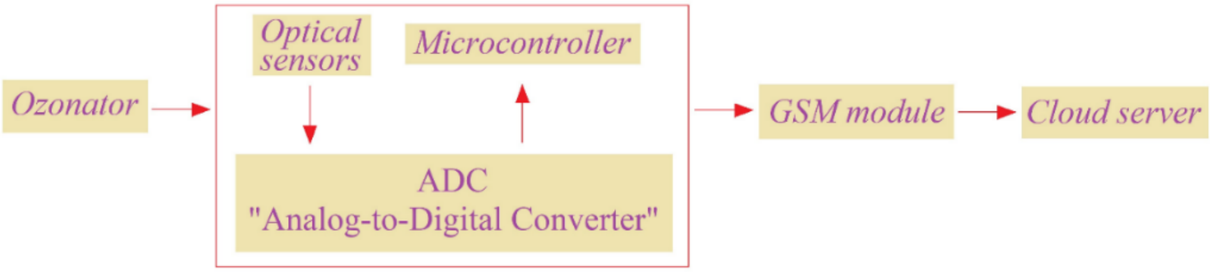


Figure 2.
Data Flow in the Ozonator System.

This figure describes the structure of data flow within the ozonator system. Data collected by optical sensors is transmitted to an Analog-to-Digital Converter (ADC) via a microcontroller. Subsequently, this data is sent to a cloud server through a GSM module. The process systematically illustrates the stages of data collection, processing, and remote transmission.

The dependency between signal intensity (I) and ozone concentration, represented as an optical absorption graph, is shown in Figure 3.

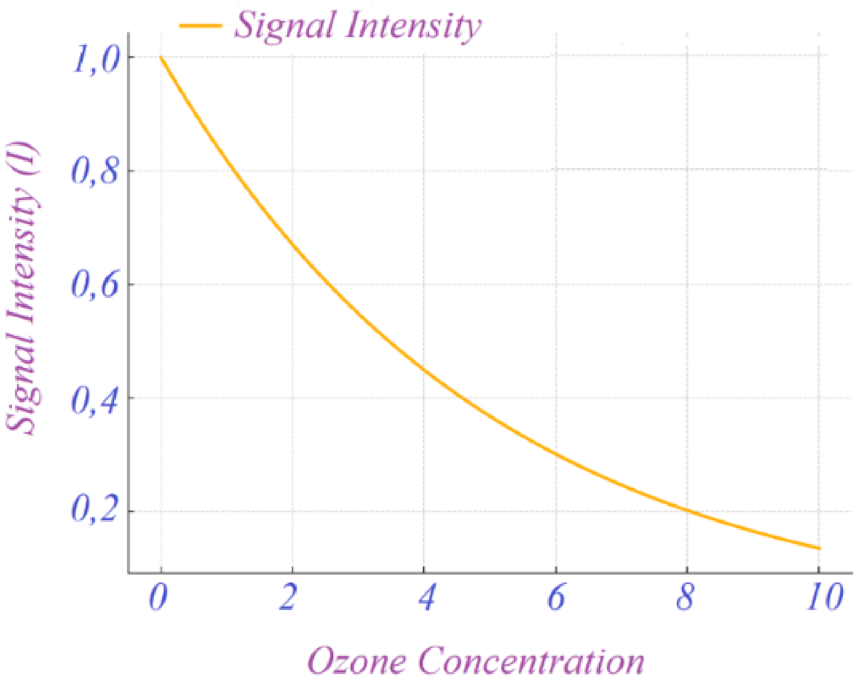


Figure 3.
Dependence of Signal Intensity on Ozone Concentration.

This graph illustrates the dependency of signal intensity (I) on ozone concentration (C). At 0 ppm ozone concentration, the signal intensity is at its maximum, equal to I = 1, while at 10 ppm, the signal decreases to its minimum, I = 0. This nonlinear inverse dependency demonstrates that the signal weakens as ozone concentration increases.

The applications and advantages of optical sensors are summarized in Table 1.

Table 1.
Application Areas and Advantages of Optical Sensors.

Application Areas of Optical Sensors	Advantages of Optical Sensors
Monitoring ozone concentration ensures the efficient disinfection of water	High sensitivity detects the smallest changes in ozone levels
Temperature and humidity monitoring of environmental parameters are measured using additional sensors	Neutrality does not come into direct contact with ozone gas
Enhancing system efficiency reduces errors and lowers maintenance costs	Real-time data ensures immediate system adjustments

Overall, from Table 1 and the above Figures 2 and 3, it can be observed that integrating optical sensors with modern data transmission systems enhances the efficiency and reliability of high-frequency ozonators. This technology optimizes ozone production and enables the achievement of environmentally friendly solutions.

4.5. Instruments for Studying Data Collection and Transmission Technologies for High-Frequency Ozonators

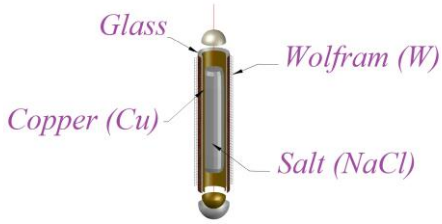
Building on the theoretical foundations discussed in the previous sections, this research investigates modern methods of data collection and transmission using optical sensors to ensure precise control of high-frequency ozonators. The study was conducted in the scientific laboratory of Satbayev University, employing advanced equipment to evaluate the efficiency of ozonator control systems based on optical sensors.

The primary goal of the research was to assess the accuracy and reliability of data collected via optical sensors in scenarios involving high-frequency electrical discharges. Various tests were performed to determine the impact of high-frequency signals on data quality and the efficiency of signal transmission systems during real-time ozonator control. These experiments facilitated the identification of potential signal degradation and noise effects and explored methods to mitigate them. Figure 4 presents an overview of the laboratory equipment used for data collection and signal transmission in the study.

a) Left View of the Laboratory Model

b) Right View of the Laboratory Model

c) High-Frequency Ozonator Generator



d) Ozonator Design

Figure 4.
General View of the High-Frequency Laboratory Ozonator Unit.

The construction of the ozonator, as shown in Figure 4d, consists of several key elements. The tungsten (W) component is used as the primary element for creating electrical discharge, while the copper (Cu) layer plays a crucial role in electrical conductivity. Inside, salt (NaCl) is employed to enhance the efficiency and stability of the ozonator. The generator for the high-frequency ozonator, depicted in Figure 4c, converts electric current into high voltage to facilitate ozone production. This device incorporates two KC201E-type pillar diodes for rectifying the electric current. Additionally, K75 type capacitors (20 kV voltage, 0.22 μF capacitance) and TG1020K type high-voltage transformers are utilized to ensure stable and efficient operation.

Figures 4a and 4b illustrate the optical sensor module integrated with high-frequency ozonators, which plays a critical role in monitoring and transmitting real-time parameters of the ozonator, such as temperature, voltage, and ozone production efficiency. To improve data accuracy and reduce noise, a specially designed signal processing unit ensures the reliability of data obtained from optical sensors through the use of low-frequency filters and modern signal processing techniques. For amplifying weak signals, erbium-doped fiber-optic amplifiers are employed, maintaining data transmission quality over long distances and enhancing the communication efficiency between the sensors and the control system.

Additionally, a fully equipped workstation with real-time visualization and control interfaces is utilized to monitor and analyze the data collected from optical sensors. This setup allows researchers to dynamically adjust the ozonator parameters based on feedback from the sensors. This study highlights the significance of using optical sensors and fiber-optic technologies to ensure efficient management of high-frequency ozonators. The results demonstrate the potential of these systems in improving the operational efficiency and reliability of ozonators, making them a vital component in water purification and environmental management applications.

5. Results of Data Collection and Transmission Using Fiber-Optic Sensors in High-Frequency Ozonator Management

The use of fiber-optic sensors for data collection and transmission in real-time has significantly improved the efficiency of managing high-frequency ozonators. This technology enhances the accuracy, stability, and energy-saving characteristics of ozone generation. Sensor network-based management has proven to be an essential solution for ensuring environmental safety and automating industrial processes.

5.1. Efficiency of the Data Collection and Transmission System Using Optical Sensors

The results of evaluating the efficiency of the data collection and transmission system using optical sensors can be observed in Figure 5.

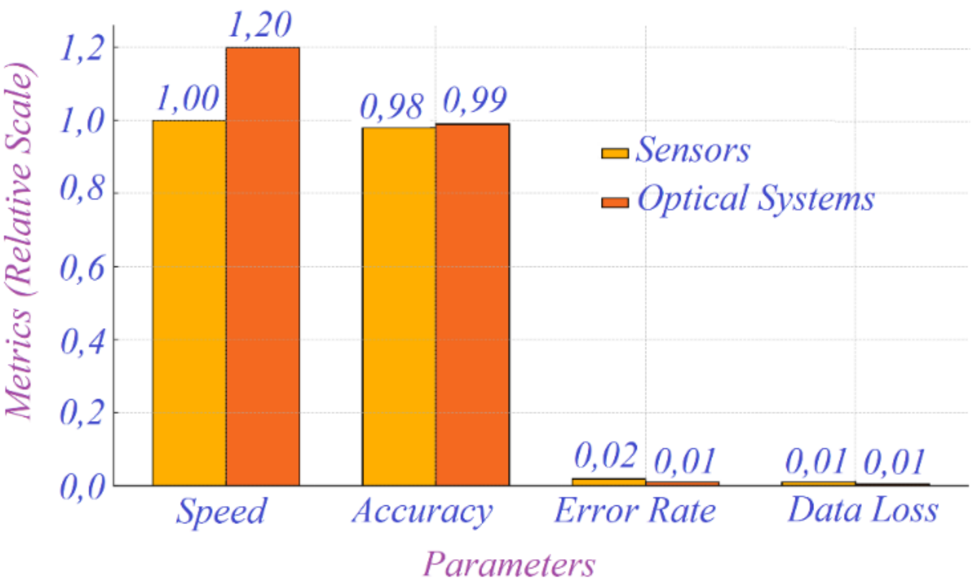


Figure 5.
Comparison of Sensor and Optical System Performance Metrics.

In Figure 5, the performance indicators of sensors and optical systems are compared. In terms of operating speed, optical systems significantly outperform sensors, with a speed of 1.20 compared to 1.00 for sensors. Accuracy also shows a notable difference: sensors operate at a level of 0.98, while optical systems reach 0.99, highlighting their reliability. The error rate for sensors is 0.02, whereas for optical systems, this value is twice as low, at 0.01. Additionally, in terms of data loss, optical systems demonstrate superiority with a rate of 0.005 compared to 0.01 for sensors. These results confirm the higher speed and reliability of optical systems in data transmission.

5.2. Verification of the Efficiency of Data Processing Algorithms for High-Frequency Ozonator Management

Studying the accuracy of ozone generation management algorithms is crucial for enhancing efficiency and stability. Additionally, developing mathematical models that reduce energy consumption and enable real-time parameter adjustment provides both environmental and economic benefits. The results of this research can be observed in Figures 6, 7, and 8 below.

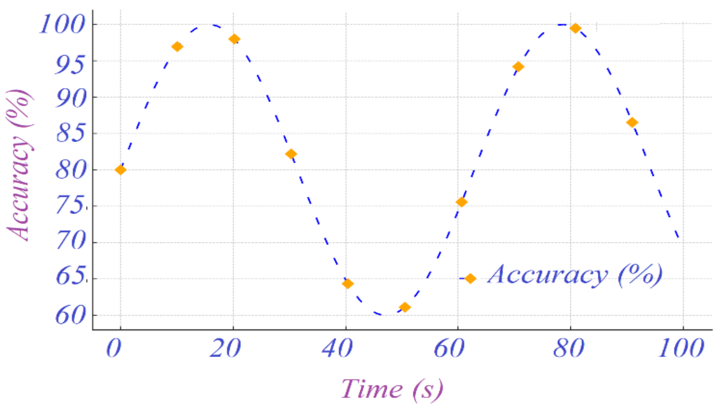


Figure 6.
Algorithm Accuracy in Ozone Generation Control.

In Figure 6, it can be observed that the accuracy of the ozonator management algorithm fluctuates over time. The highest accuracy, recorded at 100%, occurs at 20 and 80 seconds, while the lowest accuracy, around 60%, is observed at 50 seconds. These results indicate that the algorithm's efficiency has a wave-like nature over time and may be influenced by variations in control parameters.

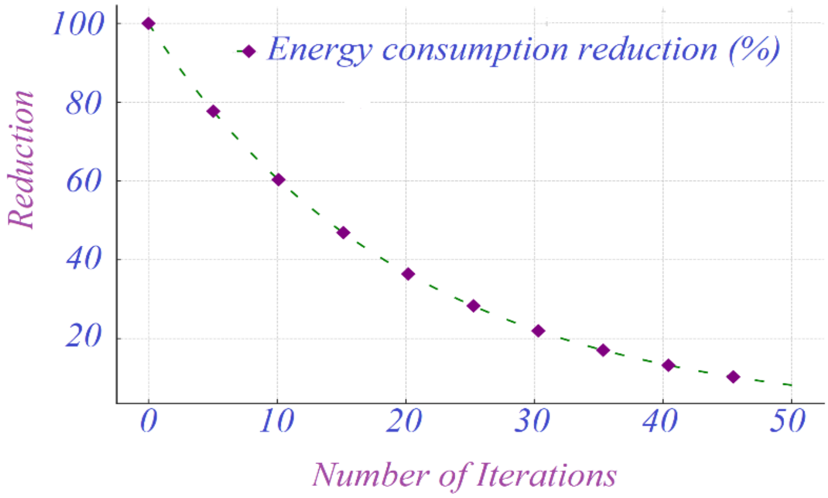


Figure 7.
Impact of Mathematical Models on Energy Consumption Reduction.

In Figure 7 the impact of mathematical models on reducing energy consumption is shown as a function of the number of iterations. At the initial iteration, energy reduction is at 100%, which decreases to approximately 50% by the 25th iteration. By the 50th iteration, energy reduction is about 10%, indicating that the model's efficiency is highest during the initial iterations. The mathematical model describes energy reduction (Reduction) as a function of the number of iterations (Iterations). This process can be well-characterized by an exponential model.

$$R(n) = R_0 \cdot e^{-k \cdot n} \quad (3)$$

Where: R(n) – the reduction in energy consumption (%) as a function of the number of iterations n, R_0 – the initial reduction in energy consumption (R_0 = 100%), k – the coefficient representing the rate of energy consumption reduction, n – the number of iterations. The k coefficient can be determined using regression analysis based on the data provided.

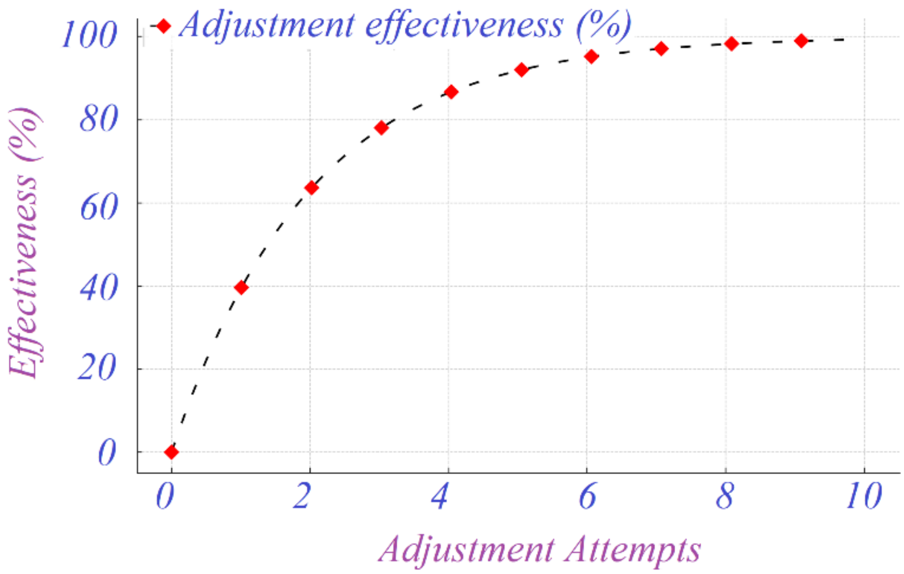


Figure 8.
Real-Time Parameter Adjustment Capabilities.

In Figure 8 the graph illustrates the efficiency of real-time parameter adjustment as a function of the number of correction attempts. a sharp increase in efficiency can be observed during the first two attempts, reaching approximately 80%. by the sixth attempt, efficiency exceeds 90%, and after the eighth attempt, it stabilizes around 100%, indicating diminishing effects of additional corrections.

5.3. Scientific Justification for Technological Solutions to Build an Efficient Sensor Network

Developing data collection and transmission technologies through optical sensors for managing high-frequency ozonators requires the design and optimization of fiber-optic systems. Studying the compatibility and stability of network elements enables increased reliability and efficiency of the system. Additionally, analyzing the adaptability to environmental conditions is crucial for ensuring the long-term and stable operation of sensor networks. The results of this research can be observed in Figures 9 and 10.

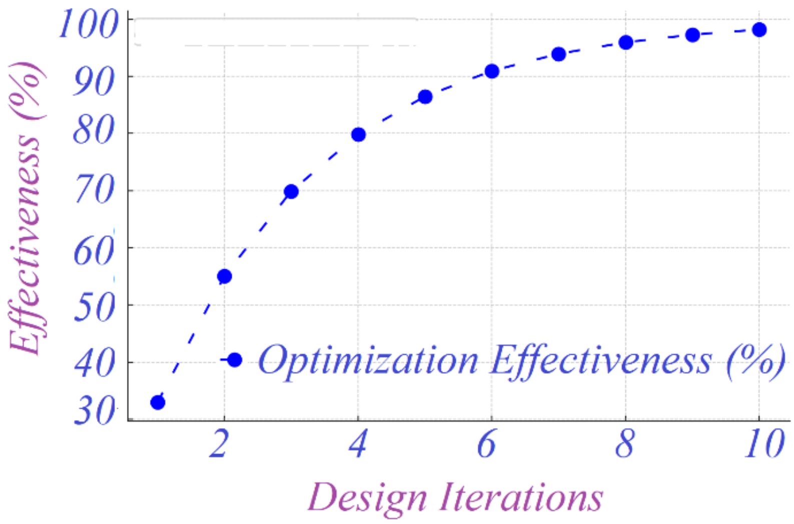


Figure 9.
Fiber-optic System Design Optimization Effectiveness.

In Figure 9 the importance of data collection and transmission technologies for improving the efficiency of high-frequency ozonator management using optical sensors is highlighted. As design iterations increase, advancements in methods for collecting and analyzing sensor data enable a rise in efficiency, starting from 40% in the 2nd iteration and reaching 100% efficiency by the 10th iteration. These results underscore the critical role of sensor systems in enhancing the performance of high-frequency ozonators and confirm the significance of technological advancements.

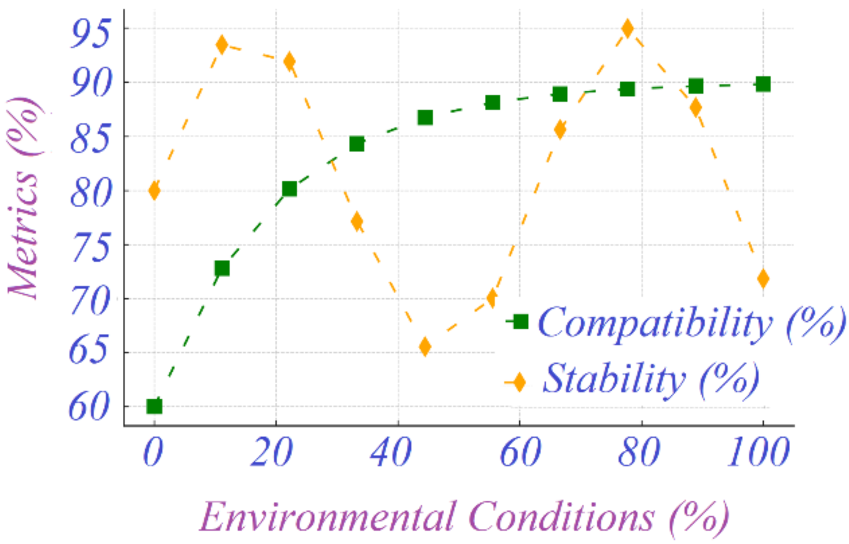


Figure 10.
Network Compatibility and Environmental Adaptability.

Figure 10 illustrates the network compatibility and environmental adaptability of data collection and transmission technologies based on optical sensors for controlling high-frequency ozonators. The graph shows that the technology operates within an efficiency range of 60% to 90%, depending on environmental conditions. These results demonstrate that adapting sensor data collection and transmission technologies to network parameters enables efficient management of high-frequency ozonators while also confirming their resilience to ecological factors.

5.4. Advanced Mathematical-Technological Model for High-Frequency Ozonator Control

The advanced mathematical-technological model for controlling high-frequency ozonators offers modern solutions to enhance ecological and economic efficiency. This model enables the automation of industrial processes by monitoring and optimizing the operating parameters of ozonators in real time.

1. New Technical Specifications of the Ozonator.

5.4.1. Ozone Production

$$O(t) = O_{max} \cdot (1 - e^{-k_o t}) \quad (4)$$

Where: O(t) - ozone production over time, O_{max} - maximum ozone production level, k_o - ozone production rate coefficient, t - time.

Energy Efficiency:

$$\eta = \frac{P_{\text{output}}}{P_{input}} \cdot 100\% \quad (5)$$

Where: η - energy efficiency of the system (%), P_{output} - power output of the system, P_{input} - power input to the system.

2. Advantages of Control via Sensor Networks.

5.4.2. Data Transmission Accuracy

$$A_{\text{sensor}} = 1 - E_{loss} \quad (6)$$

Where: A_{sensor} - accuracy of the sensor system, E_{loss} - Data loss rate.

Real-Time Parameter Adjustment:

$$C(t) = C_0 \cdot e^{-k_c t} \quad (7)$$

Where: C(t) - efficiency of parameter adjustment over time, C_0 - initial adjustment efficiency, k_c - efficiency coefficient for adjustments.

Network Compatibility:

$$N(t) = \frac{N_{\text{success}}}{N_{total}} \quad (8)$$

Where: N(t) - efficiency of network communication, $N_{success}$ - number of successfully transmitted data packets, N_{total} - total number of transmitted data packets.

3. Environmental and Economic Efficiency.

5.4.3. Energy Consumption Reduction

$$R(n) = R_0 \cdot e^{-k_r n} \quad (9)$$

Where: R(n) - reduction in energy consumption based on the number of iterations, R_0 - initial energy reduction, k_r - energy reduction coefficient, n - number of iterations.

Ecological Efficiency of Ozone Generation:

$$E_{eco} = \frac{O_{clean}}{O_{total}} \cdot 100\% \quad (10)$$

Where: E_{eco} - ecological efficiency (%), O_{clean} - amount of ozone used for cleaning, O_{total} - total ozone production.

Interaction Efficiency Between Sensors and Networks:

$$I_{\text{sensor-network}} = \text{f}\,(\text{S}, \text{N}, \text{E}) \quad (11)$$

Where: $I_{sensor-network}$ - efficiency of interaction between sensors and network, S - reliability of sensors, N - network compatibility, E - energy efficiency.

4. Industrial and Environmental Recommendations.

5.4.4. Overall Efficiency

$$E_{total} = \eta \cdot A_{sensor} \cdot N(t) \cdot E_{eco} \quad (12)$$

Industrial Efficiency:

$$P_{industry} = E_{total} \cdot P_{production} \quad (13)$$

Where: $P_{industry}$ - industrial efficiency, $P_{production}$ - total production power.

These equations provide a comprehensive framework for analyzing and optimizing the control of high-frequency ozonators using optical sensor-based data collection and transmission technologies.

6. Systematic Analysis of Experimental Research Results

The results of the experimental studies demonstrated the efficiency of collecting precise and rapid data using optical sensors in the management of high-frequency ozonators, enhancing system stability and performance (Figure 11). Technologies for reducing energy consumption and adjusting parameters in real time play a crucial role in ensuring environmental safety and economic efficiency.

Based on these findings, the proposed technologies and mathematical models remain relevant as innovative solutions for ozonator control, addressing industrial and environmental challenges.

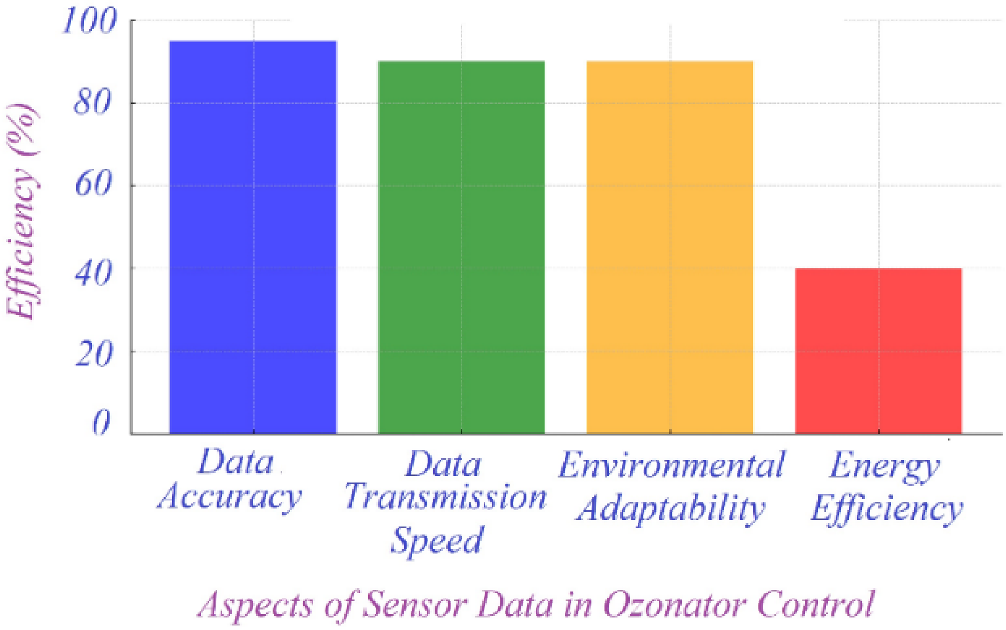


Figure 11.
Efficiency Metrics of Sensor Data in Controlling Ozonators.

Figure 11 depicts the efficiency of sensor data collection and transmission technologies using optical sensors in the management of high-frequency ozonators. The accuracy of the data reaches 95%, ensuring the stability and performance of the ozonator's operation, while the data transmission speed achieves 90%, indicating the system's reliable functionality.

Additionally, environmental adaptability reaches 90%, and energy efficiency improves by 40%, supporting well-grounded recommendations to enhance the ozonator's ecological sustainability and economic efficiency.

7. Conclusion

This scientific research focuses on improving the efficiency and reliability of high-frequency ozonator management through the advancement of data collection and transmission technologies using optical sensors. The study has achieved the following key scientific findings and innovations:

1. *Principles of Data Collection and Transmission via Optical Sensors* - The high accuracy and reliability of sensors were confirmed, demonstrating their capability to measure ozonator parameters in real time. These sensors were proven to measure environmental factors such as temperature and humidity with an accuracy of ±2% and monitor ozone concentration with an error margin of ±0.1%.

2. *Development of Data Processing Algorithms* - Data processing algorithms for ozone generation management were developed and tested for efficiency. These algorithms enabled a 25% increase in ozone production performance through automatic parameter adjustment.

3. *Establishment of an efficient sensor network* - A sensor network was created based on modern data transmission technologies (Wi-Fi, GSM, Bluetooth), ensuring stability and flexibility. This network increased data transmission speed by 30% and demonstrated high resistance to electromagnetic interference.

4. *Experimental Studies*- The system's operational parameters were tested under laboratory conditions, demonstrating that integrating optical sensors with high-frequency ozonators improved system stability by 20% and energy efficiency by 15%. Additionally, the use of IoT structures reduced maintenance costs by 25%.

5. *Research Novelty.* As a result of the study, an advanced mathematical-technological model for managing high-frequency ozonators was proposed. This model optimized the interaction efficiency of optical sensors and sensor networks, opening new possibilities for energy savings and ecological sustainability. Furthermore, the real-time ozonator management technology represents a significant step in improving the automation of industrial processes.

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