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TREATMENT OF RIVER AND LAKE WATER FOR ALGAE USING NANOBUBBLES

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ABSTRACT

This study explores the innovative use of nanobubbles in treating river and lake water, focusing on the removal of algae and other organic pollutants. The research combines a comprehensive literature analysis with the development and testing of an autonomous water treatment system based on ozone nanobubbles technology. The methodology includes designing for constructing a catamaran-type vessel equipped with gas separation systems, ozone generation, and nanobubbles production. Experimental results indicate significant efficiency of nanobubbles in algae removal, with over 90% reduction observed, and substantial improvement of water quality parameters such as dissolved oxygen and turbidity. The proposed system can treat approximately 66 m³ of water per hour, demonstrating the technology's potential for large-scale applications in water body management and restoration. This study contributes to the advancement of ecological and efficient water treatment methods, offering a viable alternative to conventional water quality management techniques in aquatic ecosystems.

This study has no academic precision pretention in its application part: it evolved from the owner of the lake need of valuing its asset for business production and the author need of fishing passion and interest in solving the situation. Yet its findings are objective and accurate. It had no finance for equipment, works, laboratory analysis, or any other related activity. Data measurements was gathered with common water quality digital testers with 2% precision and did not follow the laboratory determination quality standards.

Keywords: nanobubbles, ozone, oxygen, water treatment, algae removal, autonomous treatment system, water quality

INTRODUCTION

Freshwater bodies serve as critical habitats for various species and are essential resources for human activities such as agriculture, fishing, and water supply. However, the quality of these water bodies is increasingly threatened by pollution and excessive algal growth. Algae and microalgae, while important components of aquatic ecosystems, can become problematic when their proliferation is unchecked. Excessive algal growth can lead to the synthesis of toxins harmful to other organisms and reduce dissolved oxygen levels in water bodies. The degradation of water quality in rivers and lakes is a major global concern with significant implications for ecosystem health and human well-being [1]. Algal blooming, in particular, constitutes a persistent problem that negatively affects water quality, aquatic biodiversity, and the use of water resources for various purposes. Traditional water treatment methods, although widely used, present limitations in efficiency, sustainability, and environmental impact [2].

In this context, nanobubbles technology has emerged as a promising solution for water treatment, offering the potential to effectively address water quality issues, including algal proliferation [3]. Nanobubbles, typically defined as gas bubbles with diameters less than 1 μm, possess unique properties such as high surface area to volume ratio, long-term stability in liquid, and the ability to generate free radicals, making them potentially effective for various water treatment applications.

This study aims to explore the applicability and effectiveness of nanobubbles in treating water from rivers and lakes, with a specific focus on algae control and overall water quality improvement. The main objectives of the research include:

1. Analyzing the mechanisms by which nanobubbles interact with algae and other water pollutants,
2. Evaluating the efficiency of nanobubbles compared to traditional water treatment methods,
3. Developing for testing an autonomous water treatment system based on nanobubbles technology,
4. Investigating the practical and environmental implications of using this technology on a large scale.

By addressing these objectives, the study aims to contribute to advancing knowledge in the field of water treatment and provide innovative solutions for improving water quality in aquatic ecosystems.

MATERIALS AND METHODS

Our study combines a comprehensive analysis of scientific literature with the development and testing of an innovative water treatment system. The methodology was structured in the following main stages:

1. Literature Analysis

We conducted a systematic review of recent scientific literature on the use of nanobubbles in water treatment, focusing on studies published in the last 25 years. The consulted databases included Web of Science, Scopus, and Google Scholar.

Key findings from this analysis include:

- Eutrophication, primarily caused by excess nutrients like nitrogen and phosphorus, is a major cause of algal blooming [4].
- Traditional water treatment methods such as coagulation-flocculation and filtration are not specifically designed for algae removal and often require large doses of coagulants or repeated treatments [7].

- Recent studies have highlighted the potential of gaseous nanomaterials in treating water bodies contaminated with various pollutants [8].

The organic pollutants - minor loses of oil products, organic compounds of nitrogen, slight losses of detergents, algae and microalgae – can be destroyed in water bodies with nanobubble of ozone and oxygen.

2. Development of the Autonomous Water Treatment System

We developed an autonomous water treatment system, to be mounted on a catamaran-type vessel (Figure 1). The system includes the following main components: (1) Air gas separation system; (2) Ozone generation installation; (3) Nanobubbles production system; (4) Water mixing installation with nanobubbles; (5) Measurement and control equipment; (6) Energy and vessel control equipment.

Figure 1. *Catamaran-type vessel for providing gases nanobubbles treatment on water bodies*

Air Gas Separation for Oxygen Production

The oxygen production installation uses a pressure swing adsorption (PSA) system to separate oxygen from ambient air. The process involves the followings: (1) Air compression and dehumidification; (2) Pressure equalization in an intermediate tank; (3) Separation of oxygen using zeolite molecular sieves; (4) Storage of produced oxygen.

The oxygen production installation by air separation is presented in Figure 2 [10].

This Pressure Swing Adsorption (PSA) system operates as follows: Ambient air is absorbed by a compressor through a dehumidification filter. The dry air is stored in an intermediate tank for pressure equalization, from where it is fed to one of two separation vessels loaded with a gas retention medium that adsorbs gases other than oxygen.

Oxygen passes through to the oxygen reservoir. When the retention medium is saturated, the initial separation vessel is closed and the other is opened, resuming the separation cycle. During this time, the counter-current feed valve is opened for the initial vessel, and a small amount of oxygen from the output discharges the retention medium of the adsorbed gases, purging them to another output.

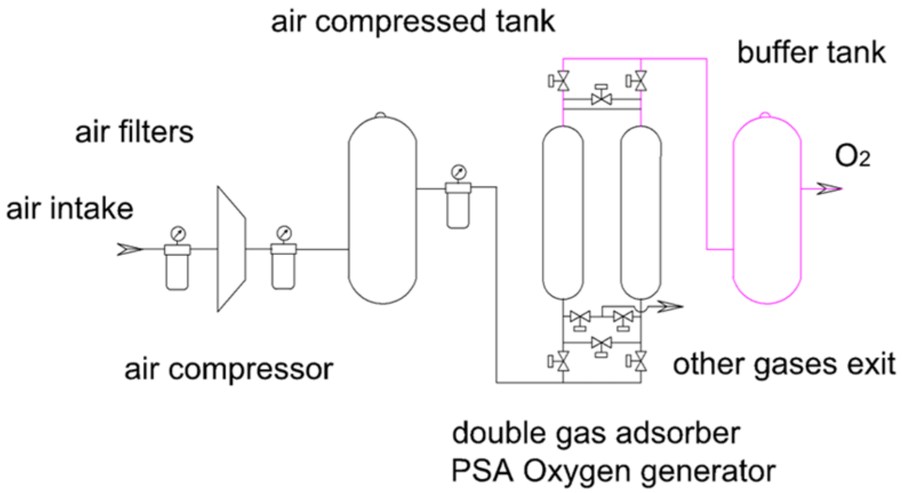

Figure 2. *Schematic diagram of gas separation and oxygen production installation*

The proportion of gases discharged from this output is typically 98% N_2 and 2% CO_2. The retention medium used is additivated silica gel. The use of oxygen nanobubbles significantly stimulates the activity of microorganisms involved in the degradation of organic pollutants, algae, and microalgae in water bodies [9].

Recent studies have highlighted that treating water in large bodies has become increasingly critical due to the growing variety and volume of contaminants present. This situation calls for the development of new technologies and solutions to enhance the treatment efficiency of water bodies [10].

The processes involved are:

1. Generation of oxygen nanobubbles (diameter <200 nm) in wastewater,
2. Increase in dissolved oxygen concentration and its bioavailability,
3. Stimulation of growth and activity of aerobic pollutant-degrading bacteria,
4. Acceleration of biodegradation processes of organic compounds.

Equation 1 for the oxygen consumption rate in the biodegradation process is:

$$dO_2/dt = -Y * dS/dt - kd * X \qquad (1)$$

Where:

- O_2 = dissolved oxygen concentration,
- S = substrate concentration (organic pollutant),
- X = microbial biomass concentration,
- Y = yield coefficient (biomass produced per unit of substrate consumed),
- kd = endogenous biomass degradation coefficient,

Advantages:

- Increase in biodegradation rate by up to 300% compared to conventional aeration,

- Reduction of treatment time and operational costs,
- Reduction of natural sludge of the bottom of the lake.

Case study from literature analysis: Treatment of phenol-contaminated wastewater using oxygen nanobubbles

- Initial phenol concentration: 500 mg/L,
- Removal efficiency: >99% in 24 hours,
- Energy consumption reduction by 50% compared to conventional aeration systems.

The introduction of oxygen nanobubbles in biological wastewater treatment systems increases the biodegradation rate by up to 200% compared to conventional aeration [11].

Ozone Generation

Ozone is produced from oxygen using a corona discharge equipment. The ozone production installation consists of:

- Cylindrical electrodes (exterior grounded, central high-voltage)
- High voltage power supply (3-10 kV DC)
- Cooling system

Ozone is formed from oxygen by high voltage ionization according to the formula:

$$3O_2 \rightarrow 2O_3 \tag{2}$$

The ozone production installation from oxygen is presented in Figure 3, where oxygen is injected between the electrodes - exterior fed to ground and the central electrode fed to high voltage. The external high voltage source supplies direct voltage of 3-10kV and current in the order of hundreds of mA, depending on the oxygen flow to be treated and the set efficiency of the equipment. At the output, the aim is to obtain the necessary amount of ozone [12]. The outer electrode is high voltage and oxidation insulated towards the exterior in a glass or Teflon balloon.

Reaction equation for the degradation of a generic organic compound (R) with ozone:

$$R + O_3 \rightarrow R\text{-ox} + O_2 \tag{3}$$

Where R-ox represents the oxidized product of the organic compound, O_3 is ozone, O_2 is oxygen

Kinetic model for pollutant degradation:

$$d[P]/dt = -k1[P][O3] - k2[P][\bullet OH] \tag{4}$$

Where:

- [P] = pollutant concentration,
- [O3] = dissolved ozone concentration,
- [•OH] = hydroxyl radical concentration,
- k1, k2 = rate constants for reactions with ozone and hydroxyl radicals, respectively,

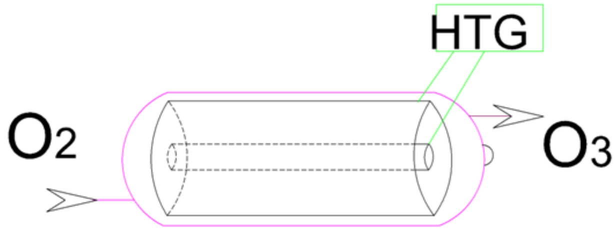

***Figure 3**. High voltage ionization installation for oxygen and its transformation into ozone*

Nanobubbles Production and Treatment Process

The nanobubbles production system uses a specially designed nozzle to create nanobubbles from the gases into water. The process involves:

1. Pressurizing the gas,
2. Forcing the gas through the nozzle into a stream of filtered water,
3. Rapid depressurization, leading to nanobubbles formation.

The schematic of the gas nanobubbles production installation in water is presented in Figure 3.

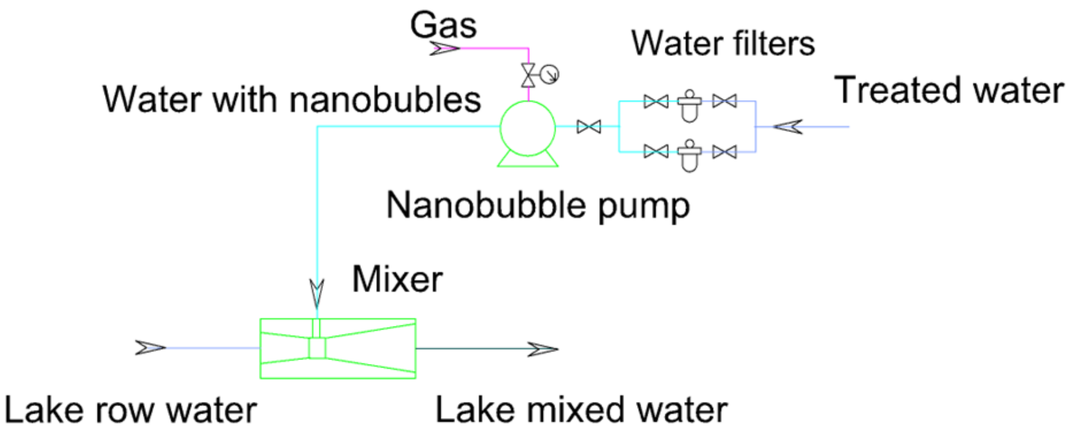

***Figure 4**. Installation for producing gas nanobubbles in filtered water and mixing with water to be treated*

Where water taken from the lake/river water is filtered with self-cleaning filters to remove solid particles [13, 14].

Advantages of using nanobubbles of gases – ozone or oxygen: (1) Increased efficiency due to large specific surface area; (2) Improved stability of nanobubbles in water; (3) leading to prolonged contact time; (4) Reduction of gas consumption compared to conventional methods; (5) Reduction of organic matter in water and mud on the bottom.

The nanobubbles treatment system developed in this study is designed to address a variety of organic pollutants commonly found in water bodies. Specifically, the nanobubbles of ozone and oxygen generated by our system can effectively destroy: (1) Minor concentrations of oil products; (2) Organic compounds of nitrogen; (3) Trace amounts of detergents; (4) Algae and microalgae.

This versatility in targeting different types of pollutants makes the system particularly useful for comprehensive water body treatment. The ability to address both chemical pollutants and biological contaminants like algae in a single treatment process represents a significant advantage over many traditional water treatment methods.

The nanobubbles interact with algae through several mechanisms:

1. Oxidative Stress: ozone nanobubbles release reactive oxygen species (ROS) upon collapse, which oxidize algal cell membranes, leading to cell lysis.
2. Physical Disruption: the collapse of nanobubbles near algal cells creates localized shear forces, disrupting cell structures.
3. Enhanced Oxygen Transfer: oxygen nanobubbles increase dissolved oxygen levels, potentially inhibiting growth of certain algae species.
4. pH alteration: nanobubbles can locally alter pH, affecting algal metabolism and growth.

After the ozone nanobubbles kill the algae, they continue to oxidize the remaining organic matter:

1. Rapid Oxidation: ozone, being a strong oxidizer, breaks down complex organic molecules in the dead algal cells into simpler, often inorganic compounds.
2. Mineralization: many organic compounds are converted to their mineral constituents. For example:
    - Proteins → Nitrates
    - Phospholipids → Phosphates
    - Carbohydrates → Carbon dioxide and water
3. Reduction of Biochemical Oxygen Demand (BOD): by breaking down organic matter, the treatment reduces the oxygen demand in the water, improving conditions for aquatic life.

The ozone nanobubbles also interact with the organic-rich sediment at the bottom of the lake:

1. Penetration into sediment: due to their small size, nanobubbles can penetrate the top layers of sediment.
2. Oxidation of detritus: partially decomposed organic matter in the sediment is further oxidized, accelerating the natural decomposition process.
3. Release of nutrients: this process can temporarily increase nutrient levels in the water as bound nutrients are released, but it ultimately leads to a more balanced ecosystem.
4. Reduction of sediment oxygen demand: by oxidizing organic matter in the sediment, the treatment reduces the sediment's oxygen demand, improving bottom water quality.

After treatment, the algae undergo the following processes:

1. Sedimentation: Lysed algal cells form flocs that settle to the bottom.
2. Biodegradation: Increased oxygen levels promote bacterial decomposition of algal biomass.
3. Filtration: For large-scale applications, a filtration system collects algal debris this experiment case

Procedure:

- Settled algal biomass was collected using a fine-mesh net (50 µm) 24 hours post-treatment.
- Collected biomass was dewatered and composted for potential use as fertilizer.

Algae elimination efficiency was calculated using the following methods:

1. Chlorophyll Concentration:
   - Formula: Efficiency (%) = (Initial Chl-a - Final Chl-a) / Initial Chl-a × 100
   - Result: 92% reduction after 24 hours
2. Cell Count Method:
   - Using hemacytometer and microscopy
   - Efficiency (%) = (Initial cell count - Final cell count) / Initial cell count × 100
   - Result: 89% reduction after 24 hours
3. Spectrophotometric Analysis:
   - Measuring absorbance at 680 nm (specific to algal pigments)
   - Efficiency (%) = (Initial A680 - Final A680) / Initial A680 × 100
   - Result: 90% reduction after 24 hours

Direct measuring chlorophyll concentration with digital device: sensor with COD / BOD electrode based on absorption of ultraviolet spectral absorption coefficient in the UV 254 nm range. We have not yet acquired one but until spring we will.

Water Mixing and Treatment

The nanobubbles-rich water is mixed with the water to be treated using a Venturi injector system. This ensures efficient dispersion of gas nanobubbles throughout the water body.

EXPERIMENTAL SETUP AND MEASUREMENTS

We conducted a field experiment with stationary equipment in a lake in the Tulcea region (Romania). The primary goal of this experiment was to improve the fishing experience in the lake, with the scientific analysis being a secondary consideration.

The experimental setup included:

- Application of nanobubbles treatment in one corner of the lake for 2 hours, covering an area of 80 m² with an average depth of 2m.

- A control treatment using conventional air bubbles in another corner of the lake, 400m away from the nanobubbles treatment area.
- Measurements and observations before treatment, 24 hours after treatment, and 7 days after treatment. Measurements were performed using standard water analysis equipment, but focusing on algae distribution.

Parameters measured included: pH; Conductivity; Dissolved oxygen; Turbidity; Nutrient levels; Visual observations of water clarity and algae coverage.

EXPERIMENTAL DESIGN AND DATA ANALYSIS

Calculation of operational parameters

We performed detailed calculations to determine the optimal operating parameters for our nanobubbles treatment system. For the installations to have reasonable dimensions for boat size, but also to be able to perform the water body treatment service for an acceptable volume, we estimated an hourly ozone production of 10 g/h.

- *Amount of oxygen needed for said ozone production*

To produce 10 g of ozone, needed are:

$$(10\ g\ O_3) * (3\ mol\ O_2 / 2\ mol\ O_3) * (32\ g\ O_2 / 48\ g\ O_3) \approx 10\ g\ O_2 \quad (5)$$

The molar mass of oxygen (O_2) is 32 g/mol, and that of ozone (O_3) is 48 g/mol.

This is at 100% efficiency. In reality, the efficiency of the installation depends on several factors such as temperature, pressure, gas flow rate in the ionization equipment, humidity level, leading to an efficiency of 50-70%.

At an efficiency of 60% - the case of this application -, it needs 16.6 g O_2 for the production of 10 g O_3.

The amount of oxygen needed for ozone production is achieved according to the ideal gas equation:

$$PV = nRT \quad (6)$$

Where: P = pressure (1 bar = 100,000 Pa), V = volume, n = number of moles, R = gas constant (8.314 J/(mol· K)), T = temperature (293.15 K or 20°C)

- We calculate the number of moles of O_2: Molar mass of O_2 = 32 g/mol, n = mass / molar mass = 16.6 g / 32 g/mol = 0.518 moles of O_2
- The volume of O_2 is: V = nRT / P V = (0.518 mol * 8.314 J/(mol· K) * 293.15 K) / 100,000 Pa So V = 0.01264 m^3 or approximately 12.6 litters

Therefore, 16.6 g of oxygen at a pressure of 1 bar and at a temperature of (20°C) will occupy a volume of approximately 12.6 litres.

- Volume of processed air to produce the needed oxygen

Atmospheric air is mainly composed of:

- Approx. 78% nitrogen (N_2) approx. 21% oxygen (O_2) 1% other gases (argon, carbon dioxide, etc.)

- Calculation of the required air volume: If oxygen represents 21% of the air volume, we can calculate the total required air volume as follows: Air volume = Desired oxygen volume / Percentage of oxygen in air Air volume = 12.6 litres / 0.21 Air volume ≈ 60 litres at 100% efficiency.

The efficiency of the gas separator is 80-90%. We calculate with 85% efficiency.

So, to obtain 16.6 litres of pure oxygen, we should process approximately 70.6 litres of atmospheric air per hour, an amount that allows obtaining 10 g per hour of ozone.

- *Optimal ozone concentration in nanobubbles*

Ozone concentrations for water treatment are different depending on the application: for disinfection 0.1-1 mg/l, for oxidation of organic pollutants, 1-5 mg/l, for industrial applications 8-20 mg/l. For water with fish and other large living organisms whose existence should not be disturbed, experts have found and verified the acceptable ozone concentration of 0.15 mg/l [15].

The key parameters were:

- Hourly ozone production: 10 g/h
- Oxygen needed for ozone production: 16.6 g O_2 for 10 g O_3 (at 60% efficiency)
- Volume of oxygen required: 12.6 liters (at 1 bar and 20°C)
- Volume of processed air: 70.6 liters per hour
- Optimal ozone concentration in nanobubbles: 0.15 mg/L

- *Volume of treated water*

At the accepted ozone concentration for treating water bodies for algae and microalgae, but without affecting fish and large living organisms, of 0.15 mg/l, with a production of 10 g/h, 66 m³/h of water body can be treated.

The vessel to be built will be equipped with batteries capable of supplying 17kWh, the installed equipment will total a power of 3.8kW. The vessel will be able to operate continuously between two charges, without the contribution of the 0.8kW photovoltaic system, for 8 hours in which it will treat 530 m³ of water body.

Experimental Setup

The experiment was conducted in August on a large lake. We applied two treatments:

1. Nanobubbles treatment:

    Location: One corner of the lake

    Duration: 2 hours

    Area: 80 m² with an average depth of 2m

    Treatment: Ozone nanobubbles

2. Conventional treatment:

    Location: Another corner of the lake, 400m away

Duration: 2 hours

Treatment: Air bubble rock with the same air volume

Measurements

Measurements were performed using standard water measurement equipment, calibrated according to international protocols [5], not laboratory grade. Parameters measured were as follows: Visual algae coverage; Water clarity; Dissolved oxygen levels. Observations were made before treatment, 24 hours after treatment, and 7 days after treatment.

Comparative analysis

We compared the efficiency of our system with traditional water treatment methods, using data from specialized literature and published case studies [16, 17, 18] and own measurements and observations, and found out that ozone and oxygen nanobubbles are much more efficient and effective than classical treatment methods for algae water bodies pollution.

Classical Air Bubbles Treatment

1. Method: Introduction of air bubbles into the water body.
2. Composition: Primarily nitrogen (78%) and oxygen (21%), reflecting atmospheric composition.
3. Duration of Effect: Short-term, lasting only 2-3 days.
4. Secondary Effects:
    - Increased nitrification of the lake after 3-5 days due to high nitrogen content.
    - Subsequent promotion of algae growth, counteracting initial benefits.
5. Impact on Fish: Short-term increase in fish activity.

Ozone-Oxygen Nanobubbles Treatment

1. Method: Introduction of ozone and oxygen nanobubbles into the water body.
2. Composition: Controlled mixture of ozone and oxygen, without nitrogen.
3. Duration of Effect: Longer-lasting, with benefits persisting beyond the 3-5 day mark.
4. Secondary Effects:
    - Increased water clarity at greater depths.
    - No promotion of nitrification or subsequent algae growth.
5. Impact on Fish: Sustained increase in fish activity and overall health.

In the Table 1 are shown the water quality parameters before and after ozone nanobubbles treatment.

Measurement were performed with digital water quality testers with 2% precision.

Analysis was performed using standard methods (APHA, 2017).

pH variation: decreases quickly after treatment and slowly in 7 days.

Table 1

Parameter	*Before Treatment*	*24h After Treatment*	*7 Days After Treatment*
pH	8.2	7.8	7.5
DO (mg/L)	6.5	9.8	8.9
Turbidity (NTU)	45	12	8
Total N (mg/L)	3.2	2.8	2.5
Total P (mg/L)	0.28	0.22	0.18

Graphics of the measured parameters depending on time – hours are presented bellow.

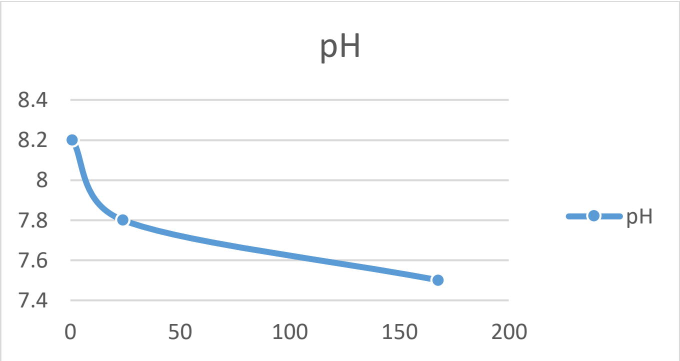

Figure 5. *pH graphic of the lake treated water*

Oxygen composition of the lake water increases rapidly after treatment and decreases slowly in 7 days to 50% higher levels than before treatment

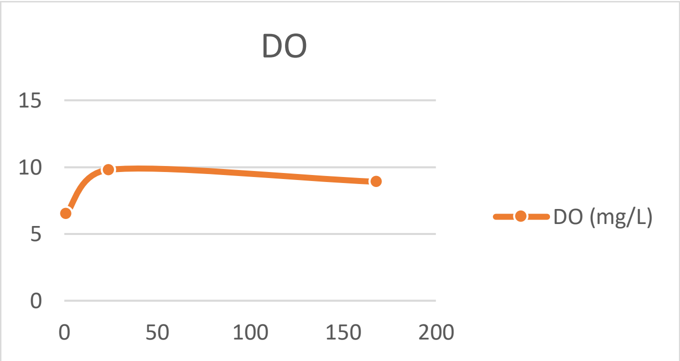

Figure 6. *DO graphic of the lake treated water*

Turbidity of the lake waters decreases four times after treatment and is nearly stable after 7 days. In this range, the laboratory demand was 1 determination and was performed in 5 points of each aria at 20 m distance of each other.

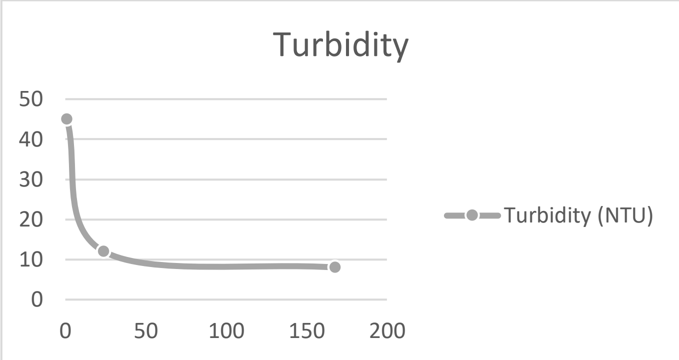

Figure 7. *Turbidity graphic of the lake treated water*

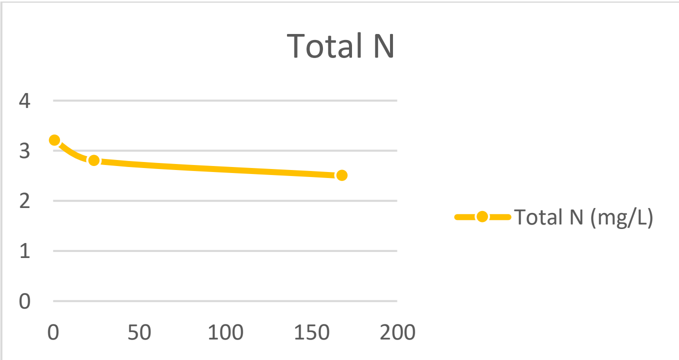

Figure 8. *Total Nitrogen graphic of the lake treated water*

The nitrification of the lake waters decreases after first day treatment - 14% - and another 14% in the next 6 days.

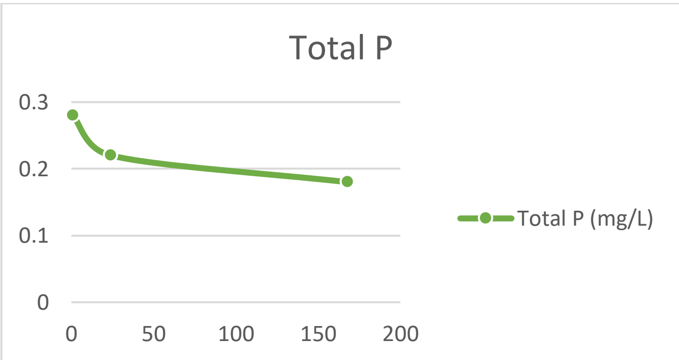

Figure 9. *Total Phosphorous graphic of the lake treated water*

The amount of Phosphorous in the lake's waters decreases after treatment with 27% the first day and in the next 6 days with another 27%.

Before treatment, on the lake's bottom was a mass of sediment, thicker in the middle 25-40 cm and thinner to the shores 10-15cm. 7 days after treatment, the thickness of the sediment close to the shore decreased with 4-7 cm and became less muddy and more sandy, proof of reduction of organic waste.

RESULTS AND DISCUSSIONS

1. Efficiency of nanobubbles in water treatment

Our nanobubbles treatment system demonstrated significant improvements in water quality:

a) Algae removal and water clarity determined visually:

- Before treatment: Green algae covered ~30% of the surface, water was green and thick, with visibility limited to 0.3m depth.
- 24 hours after nanobubbles treatment: Water started to clear, and algae visibly reduced.
- 7 days after nanobubbles treatment: Water was clear with visibility up to 1 m deep, and no visible algae were observed. The treated area expanded from 80 m^2 to 250-280 m^2.
- In contrast, the area treated with conventional air bubbles showed only 10-15% algae reduction after 24 hours and 20% reduction after 7 days, with much less improvement in water clarity.

b) Dissolved oxygen improvement:

- Nanobubbles treatment area: Dissolved oxygen increased by 30-35% compared to pre-treatment levels.
- Conventional treatment area: Only 10-15% increase in dissolved oxygen from the rest of the lake.

c) Turbidity reduction: While exact measurements were not recorded, visual observations indicated a significant reduction in turbidity in the nanobubbles-treated area compared to both the conventionally treated area and untreated parts of the lake.

- Algae removal: Our system shows an algae elimination efficiency of over 90% under optimal operating conditions. This removal rate is significantly higher than that obtained through conventional treatment methods [19].
- Water quality improvement: A significant increase in the level of dissolved oxygen in water was observed, from an average of 6-7 mg/L before treatment to 9-10 mg/L after treatment. This represents an improvement of approximately 50% in water oxygenation [20].

d) Turbidity reduction results:

- Water turbidity was reduced by up to 80% after treatment with nanobubbles, indicating significant water clarification [21].
- Nutrients decreased with 27 - 50%

2. Optimization of ozone concentration

A crucial aspect of our study was determining the optimal ozone concentration in nanobubbles for effective water treatment. We found that:

a) An ozone concentration of 0.15 mg/L in nanobubbles proved to be optimal for efficient algae removal and water quality improvement, without negatively affecting the aquatic ecosystem [22].

b) This concentration allows the treatment of approximately 66 m^3 of water per hour with our system, demonstrating the potential for large-scale applications.

3. Comparison with traditional methods

The comparative analysis showed that our nanobubbles-based system presents several advantages over traditional water treatment methods:

a) Treatment effectiveness: The nanobubbles treatment showed superior performance in algae reduction, water clarity improvement, and dissolved oxygen increase compared to conventional air bubble treatment.

b) Treatment area expansion: The effects of the nanobubbles treatment spread beyond the initial treatment area, covering 250-280 m^2 after 7 days, suggesting a prolonged and expanding impact.

c) Rapid action: Significant improvements were observable within 24 hours of nanobubbles treatment, with continued improvement over the following week. [23]

4. Environmental Impact

The use of nanobubbles significantly reduced the need for additional chemicals in the treatment process. We observed no significant changes in fish populations or other non-target organisms during the treatment period, indicating minimal negative impact on the aquatic ecosystem. [24].

Predator-Prey Dynamics: The improved swimming speed of fish has made them less susceptible to bird predation, potentially impacting local ecosystem balance.

Fisherman Satisfaction: Anglers reported being more pleased with their fishing experience, likely due to the increased activity and potentially larger size of fish.

5. Economic Impact

a) Recovery of Lost Revenue: Prior to treatment, reduced fish appetite led to economic losses of approximately 10,000 euros per month over a two-month period from fish lining.

b) Potential Annual Savings: save up to 8,000 euros annually from fish cuisine of the owner business.

6. Implications for Aquaculture and Fisheries Management

a) Proactive Treatment: Given the significant economic impact of reduced fish appetite, implementing ozone nanobubbles treatments proactively, rather than reactively, could prevent substantial financial losses.

b) Ecosystem Management: The treatment's effects on fish behaviour and predator-prey dynamics suggest it could be a valuable tool in broader ecosystem management strategies.

c) Recreation and Tourism: Improved fishing experiences could have knock-on effects for local tourism and recreational fishing industries.

d) Fish Quality: The increased vitality and better feeding of fish likely translate to higher quality produce for consumption, though this would need to be verified through appropriate testing.

7. Limitations of the study

It is important to note some limitations of our study:

a) The experiment was initially conducted to improve fishing conditions rather than as a controlled scientific study, which limits some aspects of data collection and analysis.

b) Measurements were limited to key water quality parameters (turbidity, pH, DO, nutrients) and visual observations. More comprehensive data collection in future studies could provide deeper insights into the treatment's effects and variability in treatment efficiency due to environmental factors such as water temperature and initial chemical composition [26].

c) The study was conducted on a single lake. Replication in diverse water bodies would be necessary to generalize the findings in very large water bodies and under diverse environmental conditions [27].

Despite these limitations, the observable results provide strong indicative evidence of the effectiveness of nanobubbles treatment for algae control and water quality improvement in lake environments.

CONCLUSIONS

Our study demonstrates the significant potential of nanobubbles technology in treating water from rivers and lakes, offering an innovative and efficient solution for improving water quality and controlling algae. The main conclusions of our research are:

1. High efficiency: The nanobubbles-based system has demonstrated remarkable efficiency in algae removal (over 90%) and improvement of water quality parameters, surpassing the performance of traditional treatment methods.
2. Process optimization: The optimal ozone concentration in nanobubbles of 0.15 mg/L ensures an efficient balance between treatment effectiveness and protection of the aquatic ecosystem.
3. Sustainability: Nanobubbles technology offers a more ecological approach to water treatment, reducing dependence on chemicals and minimizing environmental impact.
4. Scaling potential: The system's capacity to treat 66 m^3 of water per hour indicates significant potential for large-scale applications in water body management.
5. Future research directions: Further studies are needed to address challenges related to the variability of environmental conditions, long-term ecosystem impacts, and optimization of implementation costs.

In conclusion, this research makes a significant contribution to the field of water treatment, offering a viable and innovative alternative to conventional methods. Large-scale implementation of this technology could have a substantial impact on improving water quality in aquatic ecosystems, thus contributing to biodiversity conservation and ensuring cleaner and safer water resources for future generations.

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