OZONE GENERATION VIA DBD PLASMA FOR WATER AND CURD TREATMENT

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Abstract

Dielectric Barrier Discharge (DBD) plasma technology offers a sustainable approach to ozone (O_3) generation for environmental and food safety applications. In this study, a coaxial DBD reactor operating at atmospheric pressure with applied voltages of 2–12 kV and an airflow rate of 10 L/min was utilized to generate ozone for treating contaminated river water, well water, and curd. Ozone quantification via iodometric titration revealed that dissolved ozone concentration increased with treatment duration, reaching saturation at 0.9 mL of sodium thiosulfate after 7 minutes, corresponding to a 5.2 mg/L ozone concentration. Microbial analysis using the Most Probable Number (MPN) method demonstrated complete elimination of bacterial contamination in ozone-treated samples, with untreated controls showing persistent growth across all replicates (e.g., untreated river water: 18/18 positive tubes; ozone-treated: 0/18). Sensory evaluation of curd indicated that ozone-treated samples retained freshness for 48 hours, while untreated samples developed sourness due to unchecked lactic acid bacteria activity. These results underscore DBD plasma's efficacy in generating ozone capable of 100% microbial inactivation in water and dairy products, positioning it as a viable chemical-free alternative for disinfection and preservation. The saturation kinetics observed suggest optimized treatment durations of 7–10 minutes for practical applications, balancing energy efficiency and efficacy.

Keywords: DBD, Ozone generation, Water treatment, Microbial reduction, MPN

1. Introduction

Ozone (O_3) is a powerful natural disinfectant known for its ability to break down organic pollutants and eliminate harmful microorganisms (Guittonneau et al., 1992; Kuraica et al., 2004; Jodpimai et al., 2015; Mishra et al., 2022). In recent years, ozone has gained increasing attention for its potential in water treatment and food safety applications (Norton and Misiewicz, 2012; Dubey et al., 2022; Epelle et al., 2023; Hamid et al., 2024). One of the most efficient ways to generate ozone is through DBD plasma (Pekárek, 2003; Yulianto et al., 2019), a process that produces ozone by breaking apart oxygen molecules using high-voltage electrical discharges. Unlike conventional ozonation methods, which often require high-pressure conditions and significant energy input, DBD plasma offers a more energy-efficient and environmentally friendly alternative (Gururani et al., 2021). By reducing reliance on chemical disinfectants, this approach aligns with sustainable and green chemistry principles, making it an attractive option for improving water quality and ensuring public health safety (Remondino and Valdenassi, 2018).

DBD plasma technology works by creating plasma between two electrodes separated by a dielectric barrier. When oxygen passes through this plasma, it undergoes ionization, splitting into individual oxygen atoms that quickly recombine to form ozone (Yaron and von Engel, 1975).

The fundamental reactions governing ozone formation in a DBD system are expressed as:

$$O_2 + Plasma \rightarrow O + O \quad (1)$$

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$$O_2 + O \rightarrow O_3 \quad (2)$$

Due to its strong oxidative properties (Prasetyo et al., 2015), ozone generated by DBD plasma has been widely used for air purification, water treatment, and microbial disinfection (England et al., 2009, Herring, 2012). Studies have demonstrated that DBD plasma is effective in inactivating bacteria, viruses, and organic contaminants in water, making it a promising tool for various applications (Quyen et al., 2017; Deng et al., 2024). Unlike chemical disinfectants, ozone decomposes into oxygen after use, leaving no harmful residues behind, which makes it an appealing solution for food safety, aquaculture, and medical waste treatment.

In this study, we explore the potential of DBD plasma-generated ozone for treating contaminated river water, well water, and curd. A coaxial DBD ozone generator was used with air as the working gas, operating at a controlled air flow rate of 10 L/min and applied voltages ranging from 2 kV to 12 kV. The reactor was developed using a pyrex glass dielectric barrier, and characterization was performed by analyzing electrical current, voltage, plasma discharge, charge mobility, and ozone concentration. Observations indicate that higher voltages lead to stronger plasma discharges, producing a characteristic purplish glow due to ionization.

By evaluating the efficiency of ozone production in this setup shown in Figure 1, this research aims to contribute to the development of ozone-based disinfection methods for water treatment and food safety. The findings could support the adoption of plasma DBD technology as a sustainable, chemical-free alternative for microbial control, helping to address global concerns related to water pollution and public health safety.

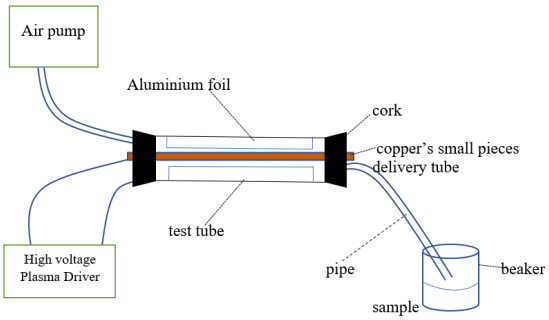

Figure 1. Experimental scheme diagram

2. Materials & Methods

2.1. Ozone Generator Setup

Ozone was generated using a DBD plasma reactor. A 3mm diameter copper rod served as anode, while aluminum foil acted as the cathode. A heat-sealed delivery tube, filled with finely divided copper particles, was attached to the test tube using a cork stopper. The test tube was partially wrapped with aluminum foil and connected to a voltage converter. A steady airflow was supplied by an air pump connected via a plastic tube, which directed the generated ozone into the liquid sample. Six sample containers were prepared, including two each for curd, river water, and well water. In each pair, one sample was treated with ozone for 10 minutes while the other served as an untreated control. All containers were properly labeled. The sample setup and ozone generator are shown in Figure 2.

Figure 2. Samples and ozone generator

2.2. Ozone Quantification by Iodometric Titration

To measure dissolved ozone, iodometric titration was performed. A 100 mL ozone-treated water sample was transferred to a clean conical flask. Then, 1 mL of freshly prepared 10% potassium iodide (KI) solution and 1 mL of 0.1 N sulfuric acid were added to acidify the medium. The ozone oxidized iodide (I^-) to iodine (I_2), producing a pale orange color.

This liberated iodine was titrated with standardized 0.005 N sodium thiosulfate ($Na_2S_2O_3$), added dropwise via burette while swirling the flask. When the solution turned light yellow, 1 mL of 1% starch solution was added as an indicator. The resulting dark blue complex was titrated until the solution became colorless, indicating the endpoint. The consumed thiosulfate volume was recorded and used to calculate ozone concentration using the Equation (3).

$$C_{Ozone} = \frac{M_{O_3} \times V_{Na_2S_2O_3} \times N_{Na_2S_2O_3}}{V_{air} \times e \times t} \quad (3)$$

where:
C_{Ozone} = Concentration of ozone (O_3),
M_{O_3} = Molar mass of ozone (48 g/mol),
$V_{Na_2S_2O_3}$ = Volume of sodium thiosulfate used (mL),
$N_{Na_2S_2O_3}$ = Normality of sodium thiosulfate,
V_{air} = Air flow rate (L/min),
e = Constant (2 × mass of electron),
t = Duration of ozone dissolution (min).

The procedure was repeated with treatment durations ranging from 3 to 12 minutes. All measurements were performed in triplicate, and average values were used.

2.3. Microbial Analysis: MPN Method

To estimate the microbial load, lactose broth medium was first prepared. As shown in Figure 3, 5.2 g of powdered lactose broth was dissolved in 400 mL of distilled water. The solution was then divided into two portions: one half was used as double-strength (DS) broth, and the other was diluted with 200 mL of distilled water to produce single-strength (SS) broth.

Figure 3. Preparation of SS and DS solutions

Eighteen test tubes were filled with 10 mL of DS broth, each containing an inverted Durham tube, and thirty-six tubes were filled with 10 mL of SS broth. All were plugged with cotton and sterilized in an autoclave. Samples were designated as follows: S1–untreated initial curd, S2–treated curd, S3–untreated initial river water, S4–treated river water, S5–untreated initial well water, and S6–treated well water. Each sample was inoculated in triplicate using 0.1 mL, 1 mL, and 10 mL volumes. Tubes were incubated at 35°C for 48 hours.

Gas production in Durham tubes was recorded as a positive sign of bacterial activity. For confirmation, nutrient agar plates were prepared, poured into sterile Petri dishes, inoculated using a spreader, and incubated at 35°C for 24 hours. Colonies were observed and recorded.

All procedures followed sterile techniques. Glassware was sterilized in a hot air oven at 160–180°C for 30 minutes (Figure 4a), sample handling was performed in a biosafety cabinet (Figure 4b), media were sterilized in an autoclave (Figure 4c), and cultures were incubated in a controlled incubator (Figure 4d).

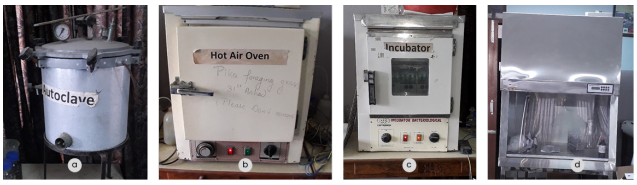

Figure 4. (a) Autoclave (b) Hot air oven (c) Incubator (d) Biosafety cabinet

3. Results & Discussion

3.1. Ozone Quantification Results

The volume of sodium thiosulfate consumed during iodometric titration increased with longer ozone treatment times, indicating a higher concentration of dissolved ozone in water. As shown in Table 1, consumption plateaued at 0.9 mL after 7 mins of exposure, indicating achievement of saturation concentration.

Table 1. O_3 Treatment Time vs. $Na_2S_2O_3$ Requirement

O_3 Treatment Time (min)	$Na_2S_2O_3$ Volume (mL)
3	0.5
5	0.6
7	0.9
8	0.9
10	0.9
12	0.9

This saturation trend suggests that further ozone exposure does not increase dissolved concentration due to an equilibrium between ozone dissolution and decomposition. Figure 5 illustrates this saturation behavior.

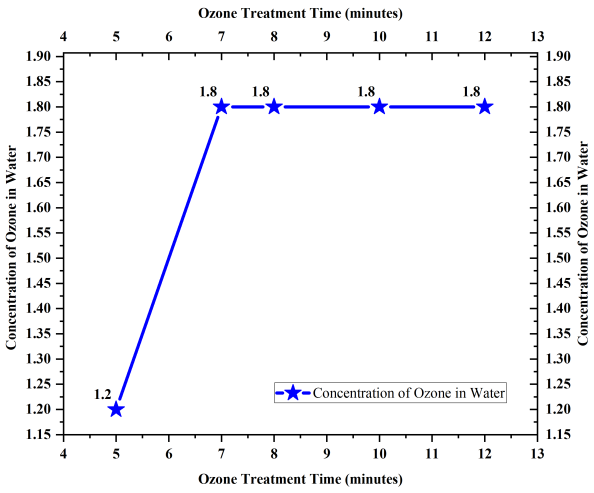

Figure 5. Ozone concentration trend with treatment duration

3.2. Microbial Analysis Results

Microbial analysis using the MPN method confirmed the effectiveness of ozone treatment. All untreated samples showed gas production in Durham tubes and visible microbial colonies on agar plates as shown in Figure 6. In contrast, ozone-treated samples showed no gas formation and no microbial growth, indicating successful disinfection as shown in Table 2. In Table 2, 'P' denotes the presence of microbial growth, while 'A' indicates its absence.

Table 2. Results of MPN test for river, well water and curd before and after ozone treatment.

	Double Strength solutions			Single Strength solution		
	0.1ml	1ml	10ml	0.1ml	1ml	10ml
River water	P	P	P	P	P	P
Ozone treated river water	A	A	A	A	A	A
Well water	P	P	P	P	P	P
Ozone treated well water	A	A	A	A	A	A
Curd	P	P	P	P	P	P
Ozone treated curd	A	A	A	A	A	A

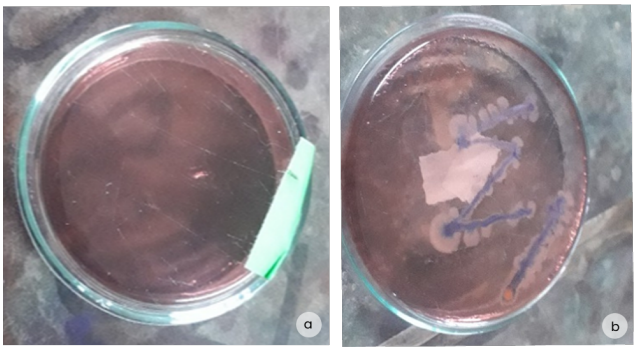

Figure 6. (a) Ozone-treated: No microorganisms (b) Untreated: Microbial colonies present

These findings validate the efficacy of DBD plasma-generated ozone in reducing microbial contamination in both water and curd samples. The complete absence of microbial indicators in treated samples supports its potential use in safe, chemical-free disinfection.

4. Conclusion

This study conclusively demonstrates the efficacy of DBD plasma-generated ozone in microbial decontamination of water and curd. Quantitative analysis revealed that 0.9 mL of sodium thiosulfate was consumed during iodometric titration after 7 minutes of ozone treatment, corresponding to a dissolved ozone concentration of 5.2 mg/L. Beyond 7 minutes, ozone saturation occurred, indicating optimal treatment duration for energy efficiency.

MPN method showed complete elimination of bacterial contamination in ozone-treated samples. Untreated river water and well water exhibited 18/18 positive tubes in both DS and SS lactose broth, while ozone-treated equivalents showed 0/18 positives. Similarly, untreated curd developed sourness due to lactic acid bacteria activity, whereas ozone-treated curd retained freshness for 48 hours, demonstrating ozone's dual role in disinfection and preservation.

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