


Characterization of Corona Plasma Ozone Generators and Analysis of Microbubble Ozone Size for Efficient Mass Transfer

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Article Info	ABSTRACT
Keywords: Ozone Plasma Corona Discharge Microbubble Ozone Mass transfer	This study aims to characterize the performance of a corona plasma ozone generator, measure the concentration of ozone produced, and analyze and compare the size of ozone microbubbles from two diffusers (C50 and C80) to evaluate the efficiency of ozone mass transfer. The method used was experimental with equipment including a VOSOCO ozone generator, Ozone Monitor, dimmer, high voltage probe, Kyoritsu ampere clamp, SANWA multimeter, flowmeter, aquarium, Apexel 12.5x macro lens, C50 and C80 diffusers, and an iPhone 11, with Python-based microbubble size analysis software for digital image processing. The results showed that the ozone generator operated at 1200 V with a linear relationship between voltage, current, and power, where the highest ozone concentration was achieved at a flow rate of 0.8 l/min. The C80 diffuser produced smaller and more homogeneous bubbles (average 3.37 μm) compared to the C50 (4.09 μm), increasing the specific surface area by 21.4% for better mass transfer efficiency. The innovation of this research lies in the development of a Python-based analysis system with an effective and affordable digital image processing approach to characterize ozone microbubble size, providing an accurate alternative for analyzing critical parameters for optimizing microbubble-based ozonation systems.
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INTRODUCTION

Ozone acts as the most powerful natural oxidizer in nature, capable of oxidizing organic and inorganic compounds and killing pathogenic microorganisms (Nur et al., 2016). Ozone has environmentally friendly characteristics that leave no residue but decompose back into oxygen, making ozone an unstable gas that will always try to release oxygen atoms through oxidation reactions before returning to its stable form (Rijal & Nur, 2015). Ozone has a wide range of applications, including clean water treatment, medical sterilization, and air purification due to its ability to kill microorganisms (Purwadi et al., 2002). Another application of ozone plasma is preservation in the storage of red chili peppers (*Capsicum annum* L), where the decay of red chili peppers is caused by the activity of microorganisms from food residues (Sefvia, 2024). Similarly, research has been conducted on the effect of

ozonation techniques and duration on horticultural crops such as chili peppers to minimize pathological damage (Meilina Sari et al., 2023). The advantage of ozone lies in its ability to break down organic pollutants, kill bacteria, viruses, and pathogens without leaving harmful residues.

Ozone production is carried out using plasma technology. Plasma is a region of electron collision reactions that are very significant for this to occur, when the energy of a gas is increased so that the gas atoms become ionized, causing the gas to release its electrons (Muhammad, 2011). The process of releasing electrons from atoms requires energy, which can be obtained from heat, electricity, or light. Atoms or particles that have been ionized (have a charge) then form plasma material (Djayanti, 2013). Plasma itself can occur naturally, but it can also be produced on a laboratory or industrial scale and utilized in various fields (Fitriani et al., 2017). Plasma can be categorized as the fourth phase of matter after the solid, liquid, and gas phases. There are various types of plasma, namely cold plasma, thermal plasma, and hot plasma, where corona discharge falls into the cold plasma category (Anggraeni et al., 2022). There are several plasma technologies used to produce ozone, including Dielectric Barrier Discharge (DBD) plasma, Double Dielectric Barrier Discharge (DDBD) plasma, corona plasma, and jet plasma. DBD plasma produces Reactive Oxygen Species (ROS), known as one of the most effective oxidizing agents in degrading colored liquid waste, especially that produced by plasma operating at atmospheric pressure (Abdurrahman et al., 2025)(Istiqomah, 2017). Corona plasma produces Reactive Nitrogen Oxygen Species (RONS). Corona discharge is a low-power electrical discharge that occurs at atmospheric pressure. This phenomenon is created by a strong electric field concentrated at the tips of sharp objects, such as fine wires or needles. The name “corona” or crown is taken from its appearance, which sailors described as light emanating from the mast of a ship during a storm. It takes the form of a soft, glowing light that spreads from the electrode. Due to its ease of generation, corona has many applications in various industries (Chang et al., 1991).

Research on corona plasma has been conducted extensively, including analysis of electric fields and current density in corona plasma determined by the physical dimensions of thin ring radii and cylinder lengths with flat ring electrodes (M.Nur, 2010), another study on the I-V characterization of negative DC corona plasma generation with a double-blade electrode configuration forming an angle to the plane in silicon oil showed that the current strength increased in line with the increase in voltage (Anggraeni et al., 2022), another study on the effect of corona plasma irradiation time at atmospheric pressure and room temperature for the decontamination of *E. coli* bacteria on glass surfaces (petri dishes) and bacterial cells grown on Endo Agar medium (Merck) and to determine the advantages of decontamination techniques using plasma compared to ultraviolet irradiation techniques (Muhammad et al., 2005). Furthermore, there is also research on determining the value of charge carrier mobility as well as obtaining current characteristics against voltage using a cylindrical wire configuration and nitrogen gas filling in positive corona plasma (Prima et al., 2018), another study on the analysis of I-V characteristic curves and electrohydrodynamic phenomena using palm oil with positive DC corona plasma using a Chisel and Center-Plane

electrode configuration configuration (Charis Munajib, Asep Yoyo Wardaya, 2022). There is also research on the application of ozone plasma from corona discharge used in processing palm oil mill effluent, where LCPKS is treated to reduce BOD and COD levels (Pamungkas et al., 2020), as well as other research on methylene blue waste with corona plasma using voltage variations (Kusumandari et al., 2019). Other research concerns the application of corona plasma for environmentally friendly sterilization that is effective in inactivating various types of pathogenic bacteria (Faruq Abdurrahman et al., 2025). There is also research on sterilization using *Escherichia coli* bacteria, where these bacteria are cultured on agar media and irradiated with corona plasma, resulting in a decrease in the number of bacterial colonies (Azka et al., 2022). Several studies on the application of corona plasma in horticulture include the effect of radiation on the viability of true shallot seeds from plasma corona (Firmansyah et al., 2024). Another study concerns the effect of variations in corona plasma radiation time on the viability, germination rate, and morphology of amaranth (*Amaranthus tricolor* L.) seeds (Nadzifah & Prihastanti, 2019). Furthermore, there is research on the design and testing of a reactor system to accelerate mangrove growth by generating corona plasma through a high-voltage DC source at atmospheric pressure (Triadyaksa et al., 2007). Research on the application of corona plasma in the textile field concerns the characteristics of electric current as a function of voltage in the corona plasma region for the treatment of textile materials using a multi-point field plasma reactor (Susan et al., 2016). The application of corona plasma is not limited to ozone generators, but is also used in the medical field for sterilizing equipment, processing material surfaces, and even cancer therapy. Although effective in producing ozone, the main challenge lies in the efficiency of transferring ozone gas into the liquid phase.

One solution to improve ozone mass transfer efficiency is to use microbubble technology. The uniqueness of microbubbles lies in their large specific surface area, slow rise velocity, and shrink-collapse phenomenon, which enhances gas diffusion. Compared to conventional bubbles, microbubbles can increase contact time and mass transfer area several times. The use of microbubbles in gas-liquid contact processes has been proven to be an effective method for improving system performance, especially when compared to conventional gas-liquid contactors. Microbubbles are defined as bubbles with a diameter between 1 and 100 μm (Gonçalves-magalh et al., 2025). These microbubbles have a number of advantages over the larger bubbles typically produced by porous diffusers in conventional systems, which generally have a diameter of 2–6 mm. This striking difference in size means that microbubbles have lower buoyancy, slower rise rates, and a much higher specific gas-liquid interface area. As a result, mass transfer processes in microbubbles occur more rapidly (John et al., 2025).

The combination of ozone and microbubble technology produces a highly efficient system for water treatment applications. This technology has great prospects, even though it is still considered a new technology in water treatment. Microbubble will certainly be at the core of various technologies that will be used in improving the aquatic environment (Khuntia et al., 2012). The smaller and more homogeneous the diameter of the microbubbles, the more optimal the ozone mass transfer performance. Previous research

has proven that microbubbles can significantly enhance gas-liquid mass transfer processes, and ozonation using microbubbles is a promising method in water or wastewater treatment (Yufei et al., 2017). Other research results conclude that in applications where a reactant needs to be transferred from the gas phase to the liquid phase (e.g., in ozonation reactors and bioprocesses), microbubble systems have been proven to provide more optimal results (John et al., 2024). These findings provide a strong basis for the wider application of this technology. Ozone microbubbles not only accelerate disinfection but also enhance the degradation of complex organic compounds such as pesticides, pharmaceuticals, and dyes. However, the effectiveness of this system is highly dependent on bubble size.

METHOD

This study used an experimental method to determine the diameter of ozone microbubbles. The research process consisted of characterizing the performance of the ozone generator, measuring ozone concentration, and analyzing the size of ozone microbubbles using image processing, as shown in Figure 1 below.

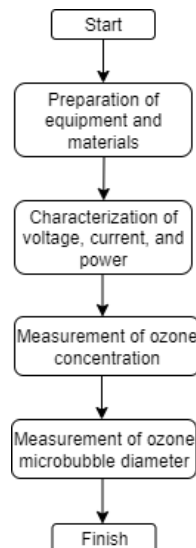


Figure 1. Research Flowchart

Experimental Setup

The experimental setup is shown in Figure 2, consisting of a VOSOCO ozone generator, Ozone Monitor, dimmer, high voltage probe, Kyoritsu ampere clamp, SANWA digital multimeter, silicone hose, 25cm x 17cm x 17cm aquarium, flowmeter (0.2-0.8 l/min), distilled water, apexel 12.5x macro lens, ultramicro nano atomized bubble plates C50 and C80.

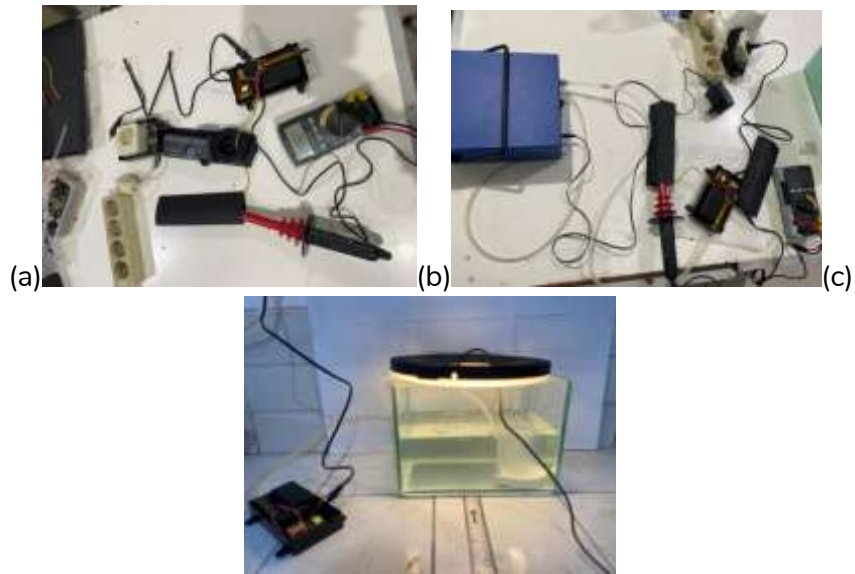


Figure 2. (a) Ozone generator characterization experiment setup (b) Ozone concentration experiment setup (c) Ozone bubble imaging experiment setup

Data analysis techniques

Data analysis techniques for characterization were performed using a multimeter to observe variations in voltage and an ammeter to determine the current value obtained. Ozone concentration was measured using an ozone monitor to determine the ozone concentration obtained in ppm units. Next, to measure the diameter of the ozone bubbles, the bubble plates were placed in an aquarium containing 4 liters of distilled water with an image capture setting of 5 cm, using an iPhone 11 camera with a sensor width of 6.86 and a macro lens with 12.5x magnification. After the image was captured by the camera, image processing was carried out in the ozone microbubble size analysis program, and the diameter measurement results on the two bubble plates were compared.

RESULTS AND DISCUSSION

Characterization of Voltage, Current, and Power

The results of data collection on the characterization of voltage, current, and power in the ozone generator used in Figure 3 are as follows.

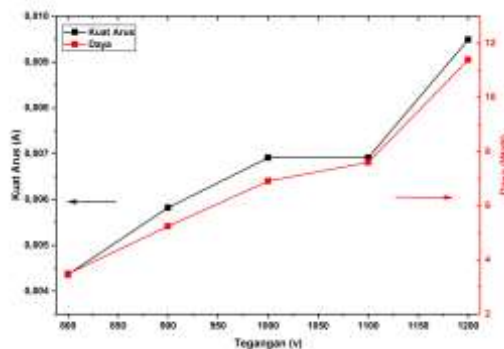


Figure 3. Characterization of Voltage, Current, and Power Graph

Figure 3 shows a graph characterizing voltage, current, and power. The ozone generator used has an output voltage of 1200 V. By using a dimmer, the voltage can be varied to obtain the results shown in the graph. The voltage obtained using the dimmer ranges from 800 V to 1200 V. From the graph, it can be seen that as the voltage increases, the greater the current value obtained. This is because the higher the voltage, the more charge is produced per unit of time, which is the formula for current, and at the same time, the higher the voltage value, the greater the power produced. This is because power is directly proportional to voltage and current. According to the results of research by (Aisyah et al., 2017), which also found that when the input voltage is increased, the current flowing will also increase sharply. Similarly, research by (Prima et al., 2018) found that the current will increase in line with the increase in voltage. The increase in current will be proportional to the voltage due to the role of electron multiplication when plasma discharge occurs with active electrodes that accumulate at the same time, causing interaction between electric charges and nitrogen molecules or atoms between the two electrodes. There are also I-V characterization results obtained by slowly applying high DC voltage, resulting in stable conditions with an increase in current. When the high voltage is increased, a gradual corona discharge will occur (Anggraeni et al., 2022).

Ozone Concentration

The results of the ozone concentration test are shown in Figure 4 below.

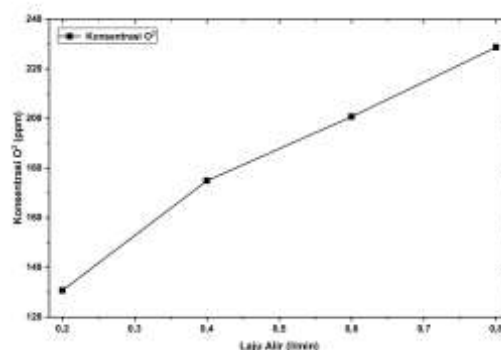


Figure 4. Ozone Concentration Graph

Figure 4 shows a graph of ozone concentration based on gas flow rate. In this ozone generator, the voltage used is the voltage from the ozone generator itself without a dimmer, which is 1200 V. The flow rate shown is not the flow rate of air from the air pump, but rather the flow rate of ozone gas that comes out because in this ozone generator, the air pump is directly connected to the corona plasma and high voltage. The flow rate of ozone gas coming out of the 1200 V voltage is 2 l/min. To vary the flow rate of ozone gas coming out, a flowmeter is used, namely 0.2, 0.4, 0.6, 0.8 l/min. Ozone concentration measurements were taken using an Ozone Monitor, with the ozone gas flowing out of the flowmeter fed into the Ozone Monitor using a silicone tube. The lowest ozone concentration was found at a gas flow rate of 0.6 l/min, while the highest ozone concentration was found at a gas flow rate of 0.8 l/min. From the graph, it can be seen that the greater the flow rate of ozone gas

produced and entering the ozone monitor, the greater the ozone concentration produced in ppm units. This is because the flowmeter functions to hold the ozone gas produced in accordance with the variations of the flowmeter.ppm units.

Analysis of Ozone Microbubble Size

The results of the analysis of ozone microbubble size are shown in the Figure below.

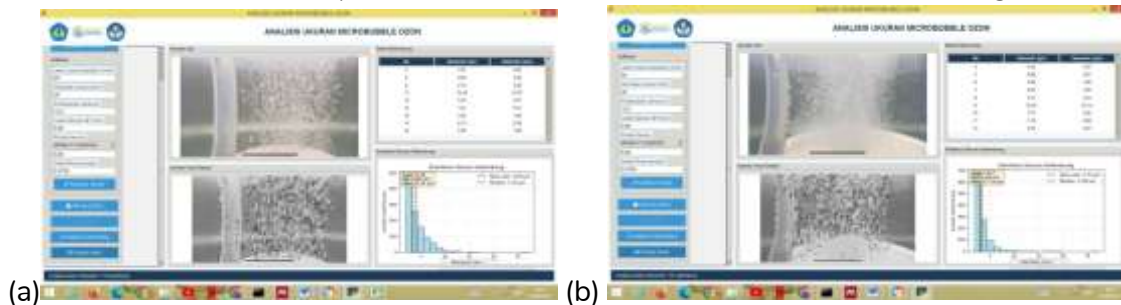


Figure 5. (a) Analysis of C50 microbubble plate size (b) Analysis of C80 microbubble plate size

Based on the measurement results, the C80 diffuser has been proven to perform better than the C50 type. The data shows that the C80 is capable of producing bubbles with a smaller average size of 3.37 μm , while the C50 produces bubbles measuring 4.09 μm . Not only are they smaller, but the bubble size distribution of the C80 is also more uniform, indicating greater stability in bubble production. From a theoretical perspective, the smaller bubble size produced by the C80 offers the advantage of increasing the contact surface area per unit volume of gas. The reduction in diameter from 4.09 μm to 3.37 μm increases the surface area by more than 21%. This has a direct impact on accelerating the process of ozone mass transfer from the gas phase into water, which is based on the principle of interphase diffusion.

The process of ozone mass transfer in microbubbles follows the mechanism of diffusion through the gas-liquid boundary layer. Smaller bubbles create a steeper concentration gradient at the interface, thereby increasing the rate of diffusion. In addition, microbubbles also trigger local turbulence that accelerates the ozone dissolution process. Another contributing factor is the length of time the bubbles remain in the water. Smaller bubbles have a slower rise speed, resulting in longer contact time with the water. The combination of a large surface area and long contact duration ultimately significantly increases the efficiency of ozone dissolution in the C80 diffuser.

This finding reinforces the basic principle in gas-liquid mass transfer processes, which states that bubble size is an important parameter that affects ozonation effectiveness. With its ability to produce smaller and more homogeneous bubbles, the C80 diffuser offers superior performance for water treatment applications. The unique properties of microbubbles have led to their widespread use across various disciplines. Evidence shows they significantly boost the efficiency of gas-liquid mass transfer. Within ozonation research, the use of microbubbles has been shown to enhance key metrics, including the

mass transfer coefficient, TOC removal, and reaction rate constant. Therefore, this method is undoubtedly a promising strategy for the treatment of water and wastewater (Yufei et al., 2017).

CONCLUSION

Based on the entire series of studies conducted, it can be concluded that the corona plasma ozone generator was successfully operated at a voltage of 1200 V with consistent output characteristics against voltage and gas flow rate variations. The characterization results showed a linear relationship between voltage increase and current and power increase, as well as a positive relationship between gas flow rate and ozone concentration produced. In the diffuser performance evaluation, the C80 diffuser proved to be superior with its ability to produce smaller and more homogeneous bubbles with an average size of 3.37 μm compared to the C50 (4.09 μm). This advantage translates into a 21.4% increase in specific surface area, which significantly supports ozone mass transfer efficiency. The innovation of a Python-based analysis system with a digital image processing approach has proven to be an effective, accurate, and affordable method for characterizing microbubble size. However, this analysis system still has several limitations. System calibration is highly dependent on the accuracy of the Field of View (FOV) parameters determined based on the specifications of the camera lens and sensor. In addition, the characteristics of microbubbles, which are very small in size, mean that the captured images do not always show a perfect circular shape due to lens distortion, light reflection, or overlap between bubbles. This imperfect shape affects the diameter calculation, which assumes an ideal circular geometry, thus potentially causing deviations in the size distribution analysis. For further research, the Python program code needs to be refined with several critical improvements. First, the implementation of a calibration algorithm based on reference markers with known sizes can improve measurement accuracy. Second, the development of a more sophisticated segmentation method using deep learning (CNN) can overcome the limitations of detecting irregular bubble shapes. Third, the addition of advanced morphological filters and overlapping bubble separation algorithms can minimize identification errors. Fourth, the integration of mathematical lens distortion correction will improve measurement precision. These improvements are expected to result in a more robust and accurate microbubble characterization system to support more precise ozonation research.

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