Int. J. Hum. Capital Urban Manage., 8(4): 457-468, Autumn 2023

International Journal of Human Capital in Urban Management
(IJHCUM)

Homepage: http://www.ijhcum.net/

ORIGINAL RESEARCH PAPER

Optimization of energy consumption of ozone generator and plasma generator in decolorization and disinfecting of water system in urban residence

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ARTICLE INFO

Article History:
Received 12 February 2023
Revised 29 June 2023
Accepted 11 July 2023

Keywords:
Color Contaminated Water
Microbial Contaminated Water
Ozone
Ozonation
Plasma

DOI: 10.22034/IJHCUM.2023.04.02

ABSTRACT

BACKGROUND AND OBJECTIVES: The water field futurology is mostly focused on the water shortage and resulting political-security crises. However, the emphasis of this study is on the water pollution crisis. This study utilizes water decolorization and microbial decontamination as novel and low-risk methods in water and water resources sanitization with the preservation of the municipal environment approach. Modern oxidation methods for pre-treatment or aid-treatment have well-attained their place in the water and wastewater treatment process to reduce microbial and chemical contamination of water. Applying light, plasma, ozone, and Ultraviolet light is one of the modern and eco-friendly methods for water treatment and disinfection with growing usage.

METHODS: In this research, various types of ozone and plasma generators, with the approach of energy consumption reduction, were manufactured for simultaneous decolorization and disinfecting of the water. All these devices consist of three main sections; frequency-increasing circuits, voltage-increasing transformers, and a reactor based on electrical discharge in gas. The simulation was performed using Orcad and PSPICE and Comsol softwares. After designing and simulation, a pilot of each of these three sections was made.

FINDINGS: Both plasma and ozone reactors, which act as light tubes with a purple color spectrum were made and optimized for water treatment in the form of tubular tubes and flat cell for volume and surface radiation. Microbial testing of 8 water samples in terms of coliform in laboratory was confirmed by the Iran Environmental Organization mpn/100ml.

CONCLUSION: After computer simulation, all three basic sections of an ozone generator device with a power consumption equal to a 30-watt lightbulb were made and optimized. By 5-minute injection of the ozone generated by this device into the water containing methylene blue as the color contamination index and Escherichia coli as the microbial contamination index, 99% of microbial decontamination was achieved, along with decolorization.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
63	3	2

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Note: Discussion period for this manuscript open until January 1, 2024 on IJHCUM website at the “Show Article.

INTRODUCTION

Although the more than three-quarters of Earth is covered by water (Shi, 2022) and 97% of the water on this planet accumulates in oceans and seas, humans provide their drinking and sanitary water from the 1% of water flowing in the rivers or stored in freshwater lakes and underground resources (Greenberg and Schneider, 2019). In the last decade, in addition to the water shortage crisis, due to the increase in population and the change in the consumption pattern, the crisis of clean water shortage also stands out (Moghadam and Samimi, 2022). On the other hand, in addition to preventing environmental pollution and emerging hygienic hazards, modern communities treat wastewater to provide a permanent and assured water resource for industry, agriculture, and other usages (Obaideen *et al*., 2022; Karbassi and Pazoki, 2015). The specific contaminators causing water contamination contain a wide range of pathogen microorganisms and chemical substances due to the leakage of municipal and hospital swages and industrial wastewater into the water resources (Mukhopadhyay *et al.,* 2022; Saini and Deepak, 2021). Eliminating contaminators that cause diseases and eliminating contaminators that make the aroma, color, and taste of water undesirable for human consumers are the two prominent reasons for water treatment. In the treatment of municipal water and wastewater, most of the fecal coliforms, a subgroup of coliforms, are investigated. *E. coli* bacteria, as the microbial contamination index in water and foodstuff, belongs to this subgroup (Bonetta *et al*., 2022). On the other hand, colors are among the first pollutants diagnosed in the water. Another source of water contamination is the leakage of wastewater and surficial and stray waters containing color and novel industrial color solvents (Arif *et al*., 2021). The interference and entering the hexagonal aromatic ring present in perfumes (Arctander, 2019) or in Fragrance (Sell, 2019), petrochemical products (Samimi and Shahriari Moghadam, 2018), pesticides (Speight, 2016; Mensah *al*., 2021), medicines, such as antibiotics (Pollak, 2011), and drugs (Myers, 2007) into the water resources shows the necessity of the applying appropriate eco-friendly methods to eliminate these contaminators in water and wastewater. Although biological treatment is known as the best and most affordable method for treatment, it cannot treat the contamination of water-soluble colors containing aromatic structures correctly (Ramos *et al*., 2021). For more than a century, chemical oxidants were initially used as disinfectants in water treatment and then used for decreasing the mineral and organic contaminators (Von Gunten, 2018). For instance, ozone, as a potent oxidant, can eliminate the minor and resistant contaminators in an aquic environment (Nashmi *et al*., 2020). Other oxidants can be used for this purpose, as well. However, adding slight amounts of chemical compounds, such as H2O2, TiO2, and peroxymonosulfate salt (Moreno-Andres *et al*., 2020) as the chemical catalysts with ozone lead to Advanced Oxidation Process (AOP) for accelerating and increasing the disinfecting (Rodríguez-Chueca *et al*., 2015) or decreasing the applied ozone dose (Rivas-Zaballos *et al*., 2022). One of the most robust synergies in the impact of ozone on water contamination is adding Ultra Violet (UV) light radiation to the ozonation process (Lu *et al*., 2022). In recent years, using chemical oxidation and advanced oxidation based on producing of highly active and reactive compounds as a pre-treatment or aid-treatment method have been proposed (Pavithra and Jaikumar, 2019). However, the presence of ozone in most AOP methods (Capodaglio, 2020), its significant effect on water pollutants, and its short half-life have made it especially prominent (Venkatesh *et al*., 2014). Ozone has shown brilliant performance in eliminating viruses, bacteria, flavor, chloramines and combined chlorine, and most organic substances (Von Sonntag and Von Gunten, 2012). As an oxidant, ozone is directly effective in eliminating water contaminators. Moreover, ozone indirectly accelerates the formation of hydroxyl radicals as a principal component of advanced oxidation (Gao *et al.,* 2019). It is proven that ozone-based AOPs are effective in the detoxification of a vast array of chemical compounds in industrial wastewater containing resistant organic substances, pharmaceutical products, pesticides, phenols, and colors (Chhaya and Srivastava, 2020). Doubtlessly, AOP is the most potent oxidant that can be added to the water since it is a combination of oxidation methods (Ahmad and Azam, 2019). However, AOPs that use UV, H_2O_2, cold plasma, and ozone could be more promising due to the production of higher amounts of hydroxyl radicals compared to separated treatments (Fan and Song, 2020). Due to the low durability of the ozone and plasma in the environment, and considering that they cannot be stored, they should constantly be produced during usage. The main disadvantage of this technology is the high-power consumption of the ozone generator device. Reducing this consumption is the best justification for optimizing these devices (da Silva *et al*., 2021). Ozone suitably terminates viruses, bacteria, flavor, chloramines, combined chlorine, and most organic substances. Moreover, catalysts lead to increasing the mass transfer of O_3 (Sanches-Simões *et al*., 2022). In addition to the states of solid, liquid, and gas in materials, plasma is a state that occurs at extremely high temperatures or by electric discharge in gas. Laroussi *et al*. (2020) produced cold plasma using a resistant barrier with no charge in the room temperature and pressure. For this purpose, they insert a gas mixture containing oxygen between two flat electrodes. Then, a voltage of about several kV was applied. The benefit of this method is the low inserting power, which is between 50 to 300 W, and the large production of plasma. This team exposed two kinds of bacteria with and without outer membranes to cold plasma and examined the effects of plasma on them with the electron microscope. After 10 min, it was observed that UV light and free parts of plasma terminated both bacteria. Plasma production leads to the formation of high-energy electrons providing spatial charge and highly reactive species of Oxygen, Nitrogen, Hydroxyl Radicals (OH), atomic Oxygen (O), and superoxide. The hot plasma is produced by flame, spark, and microwave at high temperatures (Ye *et al.,* 2020). In cold plasma, however, most of the electric energy consumes to increase the electron energy, and the total gas temperature remains at room temperature level. Generally, cold plasma is a mixture of neutral electrons, ions, atoms, and molecules. Different particles in cold plasma demonstrate different energies. It means the electrons are more energetic than other particles (Czapka *et al*., 2018). Cold plasma is generated by the ionization of fluids, such as the air around a conductor with an electric charge. This type of plasma, known as ozonation plasma, has a temperature range of 300 to 400 K (Li *et al*., 2022). In physics, the formation of cold plasma is mainly investigated in pressures lower than atmospheric pressure and vacuum lamps. On the other hand, the dielectric (DBD) properties are used in industrial applications and in the production of ozone for generating a cold plasma from the atmosphere pressure, which is sustainable in the non-laboratory environment (Duarte, 2020). Two electrodes, which at least one of them is covered by dielectric, are used in this method. The distance between these two electrodes is often about a few Millimeter (mm). The voltage and frequency levels can be varied due to the applied gas. The used frequency is often 4 kHz and 20 kHz. Dielectric can be from glass, quartz, ceramic, Teflon, and polymer (Baloul *et al*., 2019). The water field futurology is mostly focused on the water shortage and resulting political-security crises (Maruyama *et al*.,2013). However, the emphasis of this study is on the water pollution crisis. This study utilizes water decolorization and microbial decontamination as novel and low-risk methods in water and water resources sanitization with the preservation of the municipal environment approach. The aim of present study is confined to the production of a Low power consumption ozone device for removal of E. coli as well as methylene blue from contaminated waters. The current investigation has been carried out in Kish Island in the year 2022.

MATERIALS AND METHODS

As Fig. 1A displays, the devices designed and manufactured for the purpose of this study to produce plasma and ozone consist of three main sections, including a high-frequency pulse-generator electric circuit, a voltage-increasing transformer, an ozone-generator plasma tube, and some subsections, such as an air blower, programmer timer, device case, circuit connections, etc.

In the other photos related to Figure 1, the circuit components are numbered to indicate the correspondence between the schematic and the photo of the device. Parts B and C and D of the Fig. 1 show the three main designed and made sections, which involve an electronic part (circuit and transformer) called driver, and the Parts D of the Fig. 1 shows tube part, called plasma reactor and ozone cell generator, as well. The task of the driver is to produce high-voltage electricity for the tube part, which has the task of producing plasma for the decomposition of oxygen available in the air and producing ozone. The manufacturing of each section is discussed in the following**.**

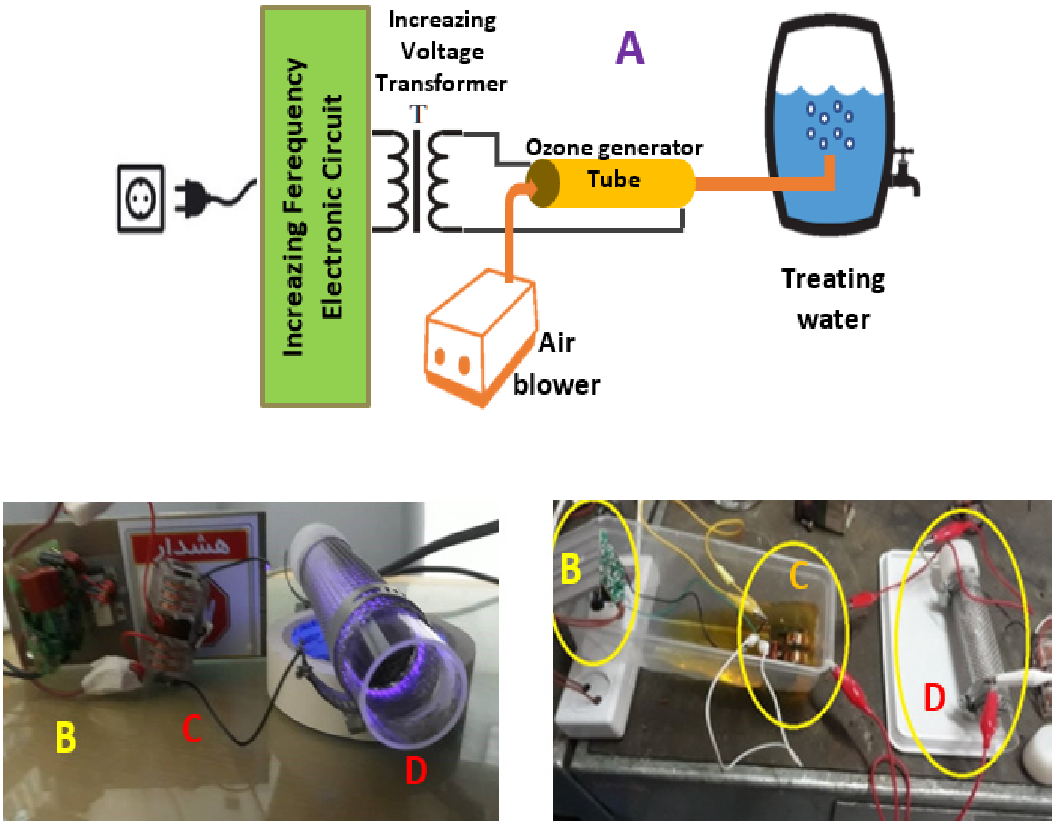

Fig. 1: (A) Main sectors of plasma and ozone generator device (B) 25000 Hz circuit (C) Ferrite-core transformer (D) Plasma, UV, and ozone reactor

Stages of Manufacturing and Testing the Circuit Pilot

A dielectric plasma ozone-generator requires a high-frequency alternating voltage (Wu *et al*., 2019). Ozone can be produced using the same municipal electricity frequency. However, the transformer and the device sizes would be excessively large due to its low frequency. Therefore, a high-frequency generator electric circuit is used for this purpose (Homola *et al*., 2020). There are many methods and circuits to produce a high-frequency voltage (Abadi *et al.,* 2022). However, regarding the availability of municipal energy sources (Murdiya *et al*., 2020), using a half-bridge inverter circuit with two switching transistors and an analog or digital time setting as a voltage converter circuit is the prevalent method (Stryczewska *et al*., 2013).

According to the Fig. 2 schematic, the designed inverter circuit for increasing the frequency of 220 V municipal electricity from 50 Hz to 50000 Hz can be designed and regulated. Initially, by rectifying the municipal electricity with a diode bridge containing four diodes, and then switching the rectified voltage reached at 310 V to 50 times in second, it turns the straight voltage of DC into a high frequency alternating voltage of AC. This board is re-designed and manufactured with 25 kHz frequency based on switching power supplies and inverter self-resonance using the general design of the electrical ballast circuits of energy-saving Light-Emitting Diodes (LED) and Compact Fluorescent (CFL) lightbulbs for producing ozone and plasma. Except for municipal electricity, the input of the inverter can be supplied by the output of an AC generator with a rectifier, battery, fuel cell, or solar photovoltaic cell (Nehari *et al*., 2019). Generally, the operation frequency of the inverter is selected as more than 15 kHz (Amjad

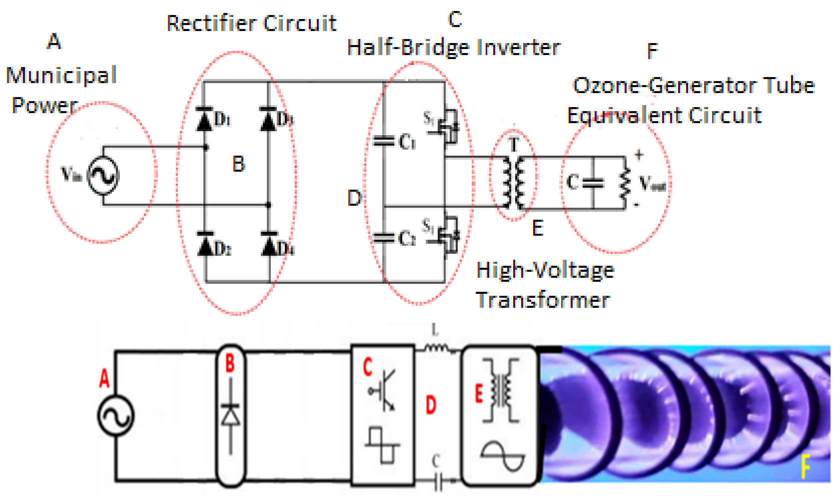

Fig. 2: Schematic and signaling of plasma and ozonation circuits (A) 220 V 50 Hz Municipal Power (B) Diode Bridge Rectifier (C) Two Switching Transistors (D) Self Tank and Regulating Capacitor (E) Ferrite-Core High-Voltage Transformer (F) Formation of Ozone-Generating Plasma In the Reactor

and Salam, 2014). Switching is usually conducted with the help of multiple switch transistors or Metal Oxide Silicon Field Effect Transistors (MOSFET) or Insulated-Gate Bipolar Transistor (IGBT) to achieve high frequency (Murdiya *et al*., 2017). In this type of converter, the criterion is increasing the number of ozone-generator reactors launches and shutting down. Therefore, a half-bridge topology can be used until 50 kHz frequencies to alter the positive and negative poles or launch and shut down the ozone-generator reactor. The aim of this action and raising the operation frequency is to minifying the transistor and produce the ozone-generator plasma, including micro sparks, and avoid the continuity of creating intense and sinking current sparks, to achieve a low-consumption frequent spark circuit (Kim *et al*., 2021).

Methods for Designing and Manufacturing of High-Frequency and High-Voltage Transformer

To increase the voltage level, after increasing the municipal electricity voltage in the switching inverter circuit made in the prior section, a voltage-increasing transformer with a high-frequency ferrite core was designed and manufactured (Fig. 3).

According to Fig.3, the electrical energy is transferred by a magnetic field from the middle of transformers that usually involves two primary and secondary windings and a magnetic core, and the electrical energy is transferred magnetically from one winding to another (Shaarbafi, 2014). By developing the power electronic science and emerging the high-frequency switching converters, giant iron-core transformers operated with municipal electricity frequency were replaced by special small high-frequency ferrite-core transformers (Hurley and Wolfle, 2013). The high-frequency transformer is much lighter and smaller than a low-frequency one since frequency has an inverse relationship with cross-section and the number of windings (Goldman, 1999). The manufactured transformer in this research is coiled for 4000 and 100 rounds on the secondary side (output) and primary side (input), respectively. During operation with the switching circuit, due to its high frequency and high-voltage output, it can launch any CFL energy-saver or fluorescent lightbulb by connecting to them (Schlüter and Shivarova, 2013). According to the Fig. 3A, by getting the CFL lightbulbs close to the circuit and transformer, due to electromagnetic interferences of operating circuits (Coca *et al*., 2011), the fluorescent tube filled with low-pressure ionizable and inflammable gas automatically turns on since the gas inside the lightbulb can be ionized and inflamed due to the establishment of the high-frequency current and injection of a strong electromagnetic field, even wirelessly and without a direct connection. This subject has been exploited

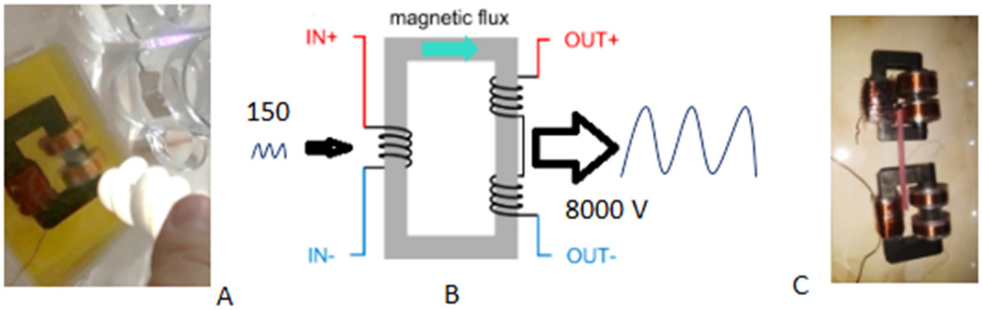

Fig. 3: (A) Operating transformer to amplify high-frequency voltage immersed in insulating oil, (B) Schematic and wiring type of increasing transformer, (C) Practical manufactured samples of transformers that would be optimized by thermal camera

in recent years to make plasma antennas instead of metal ones (Jaafar *et al*., 2017) and was frequently used in this research as a test that a fluorescent and an energy-saving lightbulb was placed in the vicinity of a high-frequency circuit and high-voltage transformer to reveal the presence of the field and its operating status. One of the heavy tasks of this study was manufacturing more than 50 handmade ferrite transformers obtained by calculation for UU-core and UR-core transformers with 10 mm, 12 mm, and 14 mm diameters for the primary winding with thin 0.5 mm wire and 70 rounds, and the secondary winding with thinner 0.01 mm wire and 3500 rounds. In practice, it was achieved with a 10% difference in accurate numbers and stable performance of the circuit. According to the Fig.3 B, C, the best responses for manufacturing and winding the transformers of this study were obtained when the transformers were precisely symmetrical in geometric terms and the secondary winding was made in the forms of two coils.

Methods for Designing and Manufacturing of plasma reactor and ozone cell generator

By establishing a high potential difference between two metal electrodes, electrons with negative charges influenced by the electrical field move from the cathode to the anode. After the saturation condition due to the dielectric barrier in the path of the electrons, if the potential difference between the two electrodes gets higher, a situation in which the current would be re-increased occurs. The nature of this increase depends on the type and pressure of the gas (Thanu *et al.*, 2019). One of the points of simulation by COMSOL software is that by knowing the mass of the fundamental particles, for instance, for simulation of plasma formation and analyzing its behavior, argon atoms can be used. Argon is a neutral gas with lower reaction and fewer collisions than air, which is a mixed gas. Argon and other noble gases are chemically ineffective and cannot form any compound. Argon plasma merely contains argon ions and electrons. For this purpose, argon is defined with an atomic number of 18, a mass number of 40 in terms of total mass, 18 electrons, 18 protons, and 22 neutrons. Then, types of electron and argon atoms collisions would be defined. The reason for this increase in electrical current is the increase of the energy and temperature of the electrons in an accelerated movement in the electric field between electrodes over time. As a result, the energy of the electrons that leave the cathode is more than the ionization energy of atoms. Some of them ionize the atoms and produce electrons and ions. These results approve the other studies of plasma generation analysis (Sener, 2021), stating that in case of acquiring adequate energy, these electrons lead to the ionization of other atoms. In other words, the ionization reactions accelerate (Ouyang *et al*., 2022). Initially, a computer simulation of the high-frequency circuit function was performed using the 2019 version of OrCAD software and the PSPICE simulator. For this purpose, new definitions and fully non-linear elements, such as DIACs, were added to the software library. Eventually, the obtained results were thoroughly coordinated with practical and laboratory signals for the circuit. The 100 times per second energy packs, in which high-frequency signals up to 25000 Hz are applied, appeared, as well.

RESULTS AND DISCUSSION

The methodology of this research was study, optimizing, device manufacturing, and laboratory. Initially, by designing and manufacturing the required circuits, transformers, and reactors, the effect of plasma and ozone generators on the decolorization and disinfection of the water contaminated by *E. coli* and the soluble color of methylene blue was proven and compared. Then, considering the energy consumption optimization for the novel ozone-plasma generator, optimizations, like a transformer with low loss, were done. The optimized circuit, transformer, and reactor were equipped as an industrial machine and then tested again for evaluation of water decolorization and microbial eliminations.

Low Power Consumption of The High-Voltage of High-Frequency

Regarding the energy consumption pattern, modern ozone, UV, and plasma equipment involves three main sections; frequency-increasing circuits, voltage-increasing transformers, and a reactor based on electric discharge in gas. By using optimized compartments containing two metal electrodes and a quartz glass dielectric layer, the particular properties of plasma can be used in ozone generation by turning hot sparks into constant micro discharges on the entire surface of electrodes. Hot ozone-generating sparks consume power up to several thousand milliampere mA. However, ozone-generating cells and tubes made in plasma devices showed a maximum of ten mA current sinking. This lower electricity consumption corresponds with lower loss, which was optimized and monitored during this research by a thermal camera of each manufactured device. Meanwhile, lower loss in the reactor of ozone and plasma corresponds to lower operating temperatures. Therefore, the need for permanent coolers will be reduced. For instance, the simplest cooling fans have 220 V to 200 mA power consumption, equal to ten times as much power as the ozone-generator reactor.

Concordance of Measured Signals with Simulation Results

The simultaneous combination of the high-frequency feed signal with low-frequency is a vital issue in detecting the ozone-generating plasma signals due to the self-resonance circuits. It means that energy is applied on electrodes in high-voltage packs but simultaneously in two different frequencies of 100 and 25000 Hz. In other words, an 8000 V energy pack with 100 Hz frequency applies in the tube, and plasma is generated suitably. On the other hand, an increasing-voltage transformer follows 25000 Hz. It could be like launching and shutting down a 25000 Hz energy source 100 times per second. Through this research and manufacturing and optimizing of device components, energy signals and high-voltage packs containing high-frequency signals were appropriately simulated, detected, and measured for the first time.

Temperature Optimizing of Circuits, Transformers, and Reactors

An ozone-generating device was manufactured and optimized by frequent production and substitution of its high-voltage power supply. Then, by plasma improvement, an ozone-plasma device was designed and manufactured. The functional optimization was done by the tests of operational continuity and temperature tests, along with the optimization of the design. Optimization of components was performed based on the photos of the infrared camera since overheating of any section refers to power loss.

Power Consumption Optimization of Circuits, Transformers, and Reactors

First, to produce hot and cold plasma, devices were manufactured. Then, the effectiveness of each of them on decolorization and disinfecting of water was examined. Eventually, every combination of the circuit, transformer, plasma cell, or ozone tube was optimized based on power consumption. All devices of this research were manufactured for simultaneous decolorization and disinfecting of water and optimized regarding power consumption. Plasma devices and small and large ozone generators were designed and manufactured up to 5 W, 10 W, and 30 W powers, respectively. In other words, the power consumption of ozone generator devices of this research was as much as a low-consumption lightbulb.

Optimization of Manufactured Devices by Testing the decolorization

Although various plasma reactors were manufactured in this study, no significant results were made for decolorization the contaminated water compared to ozonation decolorization. It was due to water turbidity, the volumetric water sample, and the low interface with testing plasma (Mohades *et al*., 2020) Ozonation acted up to 30 times better for decolorization. The comparison with the simple decolorization test was evaluated to optimize the manufactured devices since the impact of ozone on the decolorization of color-contaminated water was observable from the first minute. The decolorization test was measured after dissolving methylene blue in the well water making a mother solution as blue color water with 20 mg/liter concentration and 46 Formazine Turbidity Unit (FTU) turbidity, which turned into clear water by 6 FTU ozonation.

Microbial Test for Manufactured Devices

First, 80cc of jelly-like powder of nutrient Agar solution was boiled for 8 minutes until it melted completely. The resulting liquid was placed in a bain-marie hot water bath at 50 ^{o}C. *E. coli* was separated carefully from the contaminated sample and cultivated. This microbial suspension was used to contaminate the water samples. *E. coli* is a rod-shaped bacterium of the coliform group that is distinctive from other coliforms due to its growth and color changing in the culture media. *E. coli* is the microbial contamination index in water and foodstuff. Its presence in drinking water and food indicates contamination with intestine pathogens. Food infections and poisoning due to *E. coli* contamination are globally well-noticed and studied. A counter or filter paper with specific pores with fine lines can be used to count the *E. coli* colonies on the plate.

The *E. coli* bacteria, which has a pungent smell, has a silver-green color in nutrient Agar culture medium with methylene blue reagent. However, this color turns red by the covax reagent. Parallel with microbial tests, microbial ready-to-use kits of ColiZist were applied to perform quick and confirmatory tests. Assurance of the absence of fecal contamination bacteria index in water is critical in preserving public health. Small lidded bottles of the ColiZist kit contain nutrient Agar powder and microorganisms. By adding the testing water, it can show the presence of crucial coliforms and *E. coli* in the water sample at the same time within a day.

Best Result for Disinfection and Confirmatory Tests

Extensive microbial tests were performed in private food and drug laboratory on Kish Island. The testing water was contaminated with more than a thousand microbial colonies. Only 4 minutes of ozonation had a 99% microbicidal impact on it. The reduction of the color load was thoroughly tangible from the second minute, and the color contamination was reduced from 50 Nephelometric Turbidity unit (NTU) to 5 NTU. The official results of the tests for each water sample in the laboratory confirmed by the Iran Environmental Organization MPN/100ml, before and after the ozonation, are provided in the Tables 1 and 2.

Ozonation is practical for the water treatment industry as well as wastewater treatment. After evaluating the effect of generated ozone on eliminating *E. coli* in water and numerous confirmatory microbial tests, the ColiZist ready-to-use culture medium that ozonates the 3-day incubated sample containing thoroughly grown *E. coli* for 5 min showed that an optimized ozone-plasma device can have an appropriate performance in eliminating high concentrations of *E. coli*. Thus, it is suitable for the disinfection stage of sewage and even hospital wastewater treatment. To test this, the 3-day water sample contaminated by *E. coli*, which acted as the control sample in the previous confirmatory tests, was ozonized separately as a wastewater sample with a high *E. coli* concentration. After 4 minutes of ozonation by the manufactured device in this study, the microbial load reduction was tangible.

The Optimal Circuit with 99% Microbicide Impact and 30 W Power Consumption

In this study, more than 40 parameters were considered to manufacture and test the ozone-plasma device mainly stated in terms of voltage, current, frequency, and power. However, in practice and during manufacturing of, for example, the frequency converter electrical circuits, 13003, 13005, 13007, and 13009 transistors were used. Eventually, after optimization of thermal losses and testing the operation continuity, the 13009 transistors were optimized and applied in final circuit manufacturing. The disturbing occurred harmonies and high frequency make the specific type and high quality of 13009 necessary. It makes the manufacturer of high-frequency switches important, as well. Moreover, extensive experimental issues should be considered, during the manufacturing and resin casting of high-voltage increasing transformers. On the other hand, since the frequency of the circuits is high, making

Table 1 .Microbial testing of 8 water samples in terms of E.coli before and after the ozonation

Sample type	Water	Water + Color	Water + Microorganism	Water+ Microorganism + Color
E. coli colonies	0	9	*>1100	*>1100
Ozonated sample	Water +Ozone	Water + Color +Ozone	Water + Microorganism +Ozone	Water + Microorganism + Color +Ozone
E. coli colonies	0	0	9	0

Table 2. Microbial testing of 8 water samples in terms of coliform before and after the ozonation

Sample type	Water	Water + Color	Water + Microorganism	Water + Microorganism + Color
Coliform *colonies*	0	44	*>1100	*>1100
Ozonated sample	Water +Ozone	Water + Color +Ozone	Water + Microorganism +Ozone	Water + Microorganism + Color +Ozone
Coliform *colonies*	0	4	9	4

massive trial and error seems unavoidable to regulate the circular triode transformers that have 3 or 4 windings with five rounds. Regarding the water disinfecting and decolorization device, the main components with 28 W power consumption involving half-bridge 13009 transistors, UR14 transformer, and heatsinked large plasma tube reactor were optimized. This study provides comprehensive information for other researchers to manufacture and use. Application of various oxidant and disinfectant has been discussed by other researchers (Ahmad and Farooq, 1985; Chu *et al*., 2008; Chu *et al*., 2007; Liu *et al*., 2011). Such oxidants might include various sizes of ozone as well as radical OH. Some of the above-mentioned studies focus on dye removal and some on microbial aspects. The comparison between the present study and earlier studies clearly shows that nanobubble ozone is more effective in removal of coliform as well as color. The oxidants can be used in wastewater treatment as well as urban run-offs. For instance, the performance of oxidants (mainly radical OH) showed that while COD contents of run-offs reduces the speciation of metals might change (Ebraheim *et al*., 2022; Ebraheim *et al*., 2021). The present study showed that micro- and Nano bubbling considerably improves gas dissolution compared to conventional bubbles and hence mass transfer. It can also intensify generation of hydroxyl radical due to collapse of the bubbles, which in turn facilitates oxidation reaction under both alkaline as well as acidic conditions.

CONCLUSION

Modern oxidation methods for pre-treatment or aid-treatment have well-attained their place in the water and wastewater treatment process to reduce microbial and chemical contamination of water. Applying light, plasma, ozone, and UV light is one of the modern and eco-friendly methods for water treatment and disinfection with growing usage. In this research, various types of ozone and plasma generators, with the approach of energy consumption reduction, were manufactured for simultaneous decolorization and disinfecting of the water. First, devices were manufactured to produce both hot and cold plasma. Then, their effects on the decolorization and disinfecting of water were investigated. It was attempted to optimize the design of three main components, including the circuit, transformer, and plasma and ozone reactor, by computer simulation. The operational optimization of the pilot of the ozone generator was done by frequent substitution of its high-voltage power supply, transformer, and reactor. Therefore, an ozone-plasma device with low thermal losses and power consumption was designed and manufactured. The optimized manufactured devices were compared to the decolorization -in-water rate test, and operation continuity was optimized. Both plasma and ozone reactors were made and optimized for plasma treatment and ozonation of the water in the form of tubular tubes and surface radiation. The simulation was performed using OrCAD and PSPICE software. Microbial testing of 8 water samples in terms of coliform in laboratory was confirmed by the Iran Environmental Organization MPN/100ml. The microbicide test on the E. coli and methylene blue contaminated water was performed multiple times for the final device.

Eventually, the function of the optimized device was confirmed by microbial tests in Kish Island Official Water and Drug Laboratory with a 99% reduction of microbial load in water contaminated by E. coli. Regarding conducted studies on injecting nanobubbles into the water to increase the efficiency of low-consumption manufactured devices of this research, the injection of ozone in the forms of nanobubbles into the contaminated water is proposed. Application of the present investigation might include both residential and industrial wastewaters.

AUTHOR CONTRIBUTIONS

M.H. Mosstafavi in addition to preparing the article, was responsible for manufacturing the ozone generators and plasma generators devices. A.R. Karbasi and M. Pazoki were responsible for modification and interpretation of the results.

ACKNOWLEDGEMENT

The current study is a part of the author's doctoral thesis which was defended in 2023 at Tehran University

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

AOP	Advanced oxidation process
CFL	Compact fluorescent lamps
FTU	Formazine Turbidity Unit
IGBT	Insulated-Gate Bipolar Transistor
Khz	Killo hertz
KV	Kilo Volt
LED	Light-emitting diodes
MOSFET	Metal Oxide Silicon Field Effect Transistors
NTU	Nephelometric Turbidity unit
O3	Ozone
OH	Hydroxyl radical
W	Watts

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HOW TO CITE THIS ARTICLE

Mosstafavi, M.H.; Karbassi, A.R.; Pazoki, M., (2023). Optimization of energy consumption of ozone generator and plasma generator in decolorization and disinfecting of water system in urban residence.Int. J. Hum. Capital Urban Manage., 8(4): 457-468.

DOI: 10.22034/IJHCUM.2023.04.02

URL: https://www.ijhcum.net/article_706083.html