Ozone and anions generator for disinfection of enclosed spaces

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Abstract. After the pandemic of SARS-CoV-2, people's lives will be different. It seems that in the next period, due to the spread of SARS-CoV-2 virus worldwide, all objects, surfaces and spaces that people come in contact with must be disinfected frequently. At the same time, the atmosphere in closed spaces must be disinfected because the transmission of the virus through the air is made easier. It seems that an effective method of disinfection (viruses, bacteria, etc.) is the use of ozone generators. Ozone in the air over a certain dose affects the human respiratory system.

It is known the role of anions on human health, especially given that the vast majority will spend time indoors. Staying in homes for long periods of time has negative effects on the humans body.

The paper presents and analyze ozone, anions, and the their generators. It is presented a generator that can produce both ozone (measured with an electrochemical sensor) at a certain concentration for limited periods of time, as well as anions in high concentrations that have a beneficial effect on humans health. Air quality is measured (with an electrochemical sensor), and in conditions of low quality, the generator can provide higher concentrations of anions.

The ozone and anions generator is controlled with microcontroller development board. The flowchart of the program used in the microcontroller is presented.

1. Introduction

In December 2019, a cluster of patients with pneumonia of unknown cause was linked to a seafood wholesale market in Wuhan, China. A new dangerous and extremely contagious viruses occur: SARS-CoV-2. In the coming months of 2020, one of the largest pandemics COVID 19 in the last hundred years was to start with enormous implications for humans health and the economy [1].

Airborne particles, including bacteria, fungi and viruses, are found in the normal air. Any respiratory pathogens able to remain infectious after aerosolization and air transport. Virus containing aerosols can be formed through natural causes (eg. sneezing by a person with a respiratory virus infection), or through mechanical means (eg. when air currents around contaminated surfaces disperse the viruses into the air) [2], [3].

Ozone (O₃) is a molecule made up of three atoms of oxygen (O), and, usually, can be found in the stratosphere, where it protects life from the Sun’s harmful ultraviolet (UV) radiation and is crucial for life on Earth. However, near the ground, ozone is a harmful pollutant that causes diseases in humans, animals and plants. This ozone forms when sunlight initiates chemical reactions in the air where are pollutants, particularly nitrogen oxides and with volatile organic compounds [4].
To produce ozone, air or pure oxygen is used to passed to the ozone generator at a flow rate (e.g., using a ventilator). The energy source for production is generated by electrical discharge in a gas that contains oxygen. The oxidizing ability of ozone has long been known to be a powerful gas on pathogenic microorganisms. At the same dose of ozone viruses seem to be much stronger compared with various bacteria. Concentrations of ozone for short periods of time will disinfect water and air containing various bacteria and viruses. The effectiveness of disinfection depends on the susceptibility of the target organisms, the contact time, and the concentration (dose) of the ozone [5], [6].

At disinfections of surfaces and spaces ozone, over a certain dose, is more effective than chlorine in destroying viruses and bacteria using short contact time (up to 30 min.), the ozone decomposes rapidly (no neutralization is needed) and ozone can be produce locally [7].

Anions have been discovered for more than 100 years and are widely used for air cleaning, with positive effects on humans, animals, and vegetables. Using anions in spaces increases psychological health, productivity, and overall well-being. Also, anions could help people in allergies to dust, mold spores, and other allergens and can be used to high-efficiently remove particulate matter (with pulsed electric field) [8], [9].

To some extent by the use of anions generators device airborne pathogens transmitted virus infection between animals and inactivation of virus (>97%). Active ionizer prevented 100% from infection (on animals). The anions generators have the possibilities for rapid and simple removal of virus from air and prevent airborne transmission of viruses [3].

In the following, an analysis of ozone, anions, and their generators is presented and a generator that produce ozone and anions which can be used indoors to disinfect and improve air quality is shown.

2. Ozone

Ozone was discovered (accidentally) in 1785 by van Marum (the Dutch chemist). In the 19th century (1840) the German chemist Christian Schoenbein was given the name of ozone and identify the structure of ozone (O₃). At the end of 19th century the ozone started to be used of drinking water (the first ozonization plant in Germany in 1898). Ozone has been used commercially for disinfections over 100 years.

Some properties of ozone are: although ozone does exist naturally it is unstable and reactive gas; the ozone exists in the lower atmosphere at low concentration (0.01-0.15ppm); over 0.1 ppm the ozone can be identify by humans (through smell).

Today, there are four artificial methods recognized to ozone generation: Corona discharge (silent discharge, ionize molecular oxygen using AC high voltage) – Figure 1; ultraviolet radiation; electrolysis; radiochemical source [4], [10].

![Figure 1. Ozone generation with Corona discharge](image)

Through UV-light or Corona effects such generators of ozone use dried air or oxygen as their source gas. By adding high voltage, the oxygen molecule splits to two oxygen atoms. These atoms can then combine with other oxygen molecules which make a molecule of ozone. The ozone molecule has a strong oxidation potential which means that it reacts easily with other molecules and decomposes/transforms them. The ozone molecule is an unstable molecule which means that, if it doesn’t collide with another oxidizable molecule, it decomposes by itself to form oxygen again.
The life-span of ozone ranges from a couple of minutes to an hour depending on the surrounding conditions (temperature, pressure, pollutions, etc.). When it comes to ozone, regulations for the emission rates are set by the health administration. The limit for long-time exposure is set to 0.1ppm and the short-time exposure is set to 0.3ppm. The long-time exposure is referred to exposure during 8-hour workday, 5 days/week and the short-time exposure is set according to 15 min exposure [4], [6].

On humans the symptoms when exposed to ozone are: 0.1 – 1 ppm produce headache, irritation in eyes and throat; 1-100 ppm conduct to asthmatic symptoms, lack of appetite. If exposed to a higher dose of ozone during a shorter period the effects are irritation of the throat and coughing. These are not chronic problems and they will disappear within a couple. An easy way to make sure that the concentrations aren’t too high is to install an ambient ozone sensor. The sensor often has a set point that can give out an alarm when the concentrations are too high [11].

Disinfection is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms to prevent the spread of air and water diseases. It is important that water and air be adequately treated prior to disinfection in order for any disinfectant to be effective. When microorganisms (bacteria and viruses) were inactivated rapidly by treatment with ozone. Viruses required ozone doses of 20-112 min∙(mg/m³) (contact time (min) multiplied by ozone concentration (mg/m³)) for 90% inactivation and 47-223 min∙(mg/m³) for 99% inactivation. The ozone dose for 99% inactivation was two times higher than for 90% inactivation [12].

3. Anions
The ionization state of the atmosphere was discovered by the French engineer Coulomb in 1785 who studied electrostatic discharge, then in 1889 Giese determined that air has a electric conductivity, and in the late 19th century Thomson began the theory of ionized gases. The discovery of anions was made in the 18th century with the creation of the electrostatic generator. The favorable influence of anions on human health has been discovered since the 18th century by treating asthma. After that, at the beginning of the 19th century, anions have been used to treat mouth inflammation, rhinitis, lower blood pressure, lower blood sugar, reduce insomnia, headaches, dizziness. At the beginning of the 20th century first papers were made and the unfavorable influence of cations was determined [9].

Anions are atoms or radicals (groups of atoms), that have gained electrones (Figure 2, compared with cations that loss of electrons). Since they now have more electrons than protons, anions have a negative electrical charge. Anions are one of the two types of ions. The other type is called a cation, having a positive charge (Figure 2). Anions are termed so because they are attracted towards the anode (the positive electrode) [8].

For decades now, doctors and scientists have been studied, tested, and proven the benefits anions on humans, animals and vegetals. The negative ions produce biochemical reactions that bring a multitude of benefits such as: lowers our stress levels; boosts our energy levels; acts as a natural anti-depressant; strengthens our immune system; helps us sleep better; reinforces collagen production; improves our blood circulation; increases mental energy; balance pH and hormone levels; protect against germs in the air; reduce inflammation, irritations and infections; eliminate unwanted odor [3], [9].

Figure 2. Cation and anion
4. Ozone and anions generations using high voltage

Both ozone and anions can be formed as high voltage sources by achieving the Corona effect and even electrical discharges. Using these types of generators are convenient and easy methods. The high voltage that produces the corona effect can have other industrial applications [13-16].

To make the ozone generator can use a dielectric (ceramic) of rectangular shape, and on the side surfaces is made a system of discharge electrodes (one electrode on one surface, the other on the other surface) – Figure 3. The electrodes are placed at a distance from the edges of the dielectric to eliminate high voltage discharges between the electrodes. A tubular structure can be used, also. An alternating high voltage source (of the order of kV) can be used to supply the two electrodes. The ozone generator is placed in an electrical insulating box, which has holes, and which also has connected on one side a fan used to spread ozone. If the oxygen has inlet concentrations of 23-100%, at the exit of the ozone generator in the air it will be between 1-16% O₃ [11].

Ozone generators are typically classified by:

- The control mechanism (either a voltage or frequency unit).
- The cooling mechanism (either water, air, or water plus oil).
- The physical arrangement of the dielectrics (either vertical or horizontal) [10].
Anions are also produced by using high voltage, but with other constructive types of generators. Usually, the generators are made of two different electrodes, one of which is very sharp (there can be several peaks), discharge electrode, connected to the - polarity of high voltage, and the other electrode is a metal surface connected to + polarity of high voltage (Figure 4). In the vicinity of the tip discharge electrode there will be intense electric fields that will produce anions that will go to the other electrode. The discharge electrodes can have various configurations and lengths that will cause the production of a variable number of anions [9].

5. Experiments with ozone and anions generator

The experiments used an Arduino Nano board (Figure 5) [17], sensors for measuring ozone concentration (ZE 25 O3 type) [18] and air quality (MQ 135 type) [19], three relays, two transformers high voltage: one that supplies the ozone generator and the other (which has a high voltage diode) to power the anion generator. The program implemented in Arduino Nano, made in Arduino IDE [20], performs, on the one hand, the operation at various time intervals (24 hours a day and depending on the day of the week) of the generators (only one at a time given), and, on the other hand, the control of two high frequency power transistors that form the inverter [14], [16] and that supply (only one at one moment of time) the two generators (ozone or anions). Because the Arduino Nano does not have an internal clock, the RTC Clock (DS 1307 Real Time Clock type) is connected externally [21].

Arduino Nano is a small platform, compatible with various breadboards and built around the Atmega328P microcontroller (8 bit). It is quite similar to the Arduino Uno platform, the difference being the lack of the power plug (and the voltage stabilizer), the use of a larger number of analog inputs, its small size and a mini USB connector. For experiments, a special shield compatible with Arduino Nano can be used, which has a power plug (and voltage stabilizer) – Figure 5 [17]. Some of the most important specifications for the Arduino Nano are presented below:

- Microcontroller: Atmega 328P (Figure 5);
- Architecture: Atmel AVR 8-bit;
- Voltage: 5 V;
- Flash memory: 32 KB;
- SRAM: 2 KB;
- Speed: 16 MHz;
- Analog inputs: 8;
- PWM outputs: 6;
- EEPROM: 1 KB.

The electrical diagram for ozone and anions generators is presented in Figure 6. At digital input D10 is connected the start switch S1 and at digital input D9 is connected the stop switch S2.

The generators are controlled with Arduino Nano. At the input of the Arduino Nano two sensors are used: the ozone sensor Sn1 (ZE25 O3 type) connected at the analog input A0 and the air quality sensor Sn2 (MQ 135 type) connected at the analog input A3. The two sensors are electrochemical and are powered by an external 5V DC/1A source, which has a common ground with Arduino Nano. The
external RTC clock (DS 1307 type) is powered from the same external source (5V DC/1A) and connects to the analog inputs A4 (SDA) and A5 (SCK) of the Arduino Nano.

To the digital outputs of the Arduino Nano are connected three relays, powered at 5V, from the external source (5V DC/1A): relay K1 (pin D12) which allows the connection of the ozone generator, relay K2 (pin D8) which allows the connection of the anion generator, and relay K3 (pin D3) which allows the voltage supply of a fan that allows the spreading in a larger volume, in the room where the generators of ozone and anions are mounted. The fan also has the role of cooling the assembly (especially of the power transistors T1 and T2 mounted on the radiator).

It also use two digital PWM outputs (D4 and D5) that operate in countertime and that control, through the two power inverters I1 and I2 (ULN 2003 type, powered at 12 V DC, and the inputs are on logic 1 at 5 V DC), two power MOSFET transistors T1 and T2 (IRFZ44N type). Transistors T1 and T2 are mounted on a radiator (aluminum) properly sized. In parallel with the two transistors are mounted two fast diodes D1 and D2 (1N4001 type). The two power inverters I1 and I2 are used in order not to require (current) the digital PWM outputs of the Arduino Nano. The S sources of the two transistors T1 and T2 are connected to ground.

![Figure 6. Electrical setup for ozone and anion generators](image)

The outputs a, b and c of the inverter (Figure 6) can be connected, via K1, to the ozone generator, respectively via K2 to the anion generator. At some point, the two generators do not work simultaneously. The primary winding coils of the two generators are powered (12 V DC) from a 230V,
50Hz/12V DC, 15A switching mode power source. The ozone generator has the structure of the one shown in Figure 3, and the anion generator has the structure of the one shown in Figure 4. The anion generator has a high voltage diode D which allows to obtain a negative potential on the discharge electrode of the generator (to obtain anions). The generator is mounted in a box made of plastic that has holes for releasing ozone and anions outside. The experiments used high voltage (line) transformers used in old TVs to obtain anodic voltage for cathode ray tubes (approx. 30 kV). Experiments were performed at different inverter frequencies from 0.5 to 15 kHz. An LCD can be connected relatively easily to the Arduino Nano to display various information (in which mode the generator works, time, concentrations, etc.).

Using the experimental setup from Figure 6, the dead time control was introduced to control the two transistors T1 and T2. Inverters I1 and I2 were not used in this group of experiments. The control was performed according to the time diagram in Figure 7, and the signals measured between the G terminals and the ground of the two transistors are shown in Figure 8.

It was experimentally found that the power transistors T1 and T2 (Figure 6) together with the radiator heat up, and the digital PWM outputs from the Arduino Nano are required in the current, there is the possibility of destruction.

Figure 7. Time diagrams with signals from the Arduino Nano output (on D4 and D5) without the use of I1 and I2 inverters (Figure 6)

Figure 8. Arduino Nano output signals (on D4 and D5) without the use of I1 and I2 inverters (Figure 6), output frequency: a:500 Hz; b:1 kHz
The two inverters (I1 and I2) were introduced (as in Figure 6) and the control of the inverter was made according to the time diagram in Figure 9, and the signals measured between the terminals G and the ground of the two transistors T1 and T2 are shown in Figure 10.

By using the two inverters (I1 and I2, Figure 6), the PWM outputs (D4 and D5) of the Arduino Nano are no longer charged. The temperature reached by transistors T1, T2 and the radiator is acceptable to operate in a long duration (in the order of hours). The switching times of the power transistors for the four frequencies are listed in Table 1 (in connection with Figure 9).

**Table 1.** The switching times established, for various frequencies (from 1 to 15 kHz), for the realization of the time diagrams from Figure 9

| f (kHz) | t1-t0 (µs) | t2-t1 (µs) | t4-t2 (µs) | t5-t4 (µs) | t6-t5 (µs) |
|---------|------------|------------|------------|------------|------------|
| f=1     | 25         | 450        | 50         | 450        | 25         |
| f=5     | 5          | 90         | 10         | 90         | 5          |
| f=10    | 3          | 44         | 6          | 44         | 6          |
| f=15    | 2          | 27         | 4          | 27         | 2          |

**Figure 9.** Time diagrams with signals from the Arduino Nano output (on D4 and D5) with I1 and I2 inverters (Figure 6)

The flowchart of the subroutine for inverter control (Inverter in Figure 12) is shown in Fig.11. The flowchart follows the signals from Figure 9. In the logic diagram G1 is the output D4, and G2 is the output D5 from Arduino Nano.
After using several frequencies to control the inverter (according to Table 1) it was established that at the frequency of 15 kHz the generators work the most stable and best. For this frequency, experiments were performed for different windings in the primary circuit of the voltage transformers (Figure 6).

The current absorbed from the switching source of 12 V DC/15A and the length of the electric arc were measured (Table 2).

Table 2. Influence of the number of turns in the primary winding on the current consumed by the low voltage DC power source

| f (kHz) | 2x7 turns | 2x10 turns | 2x11 turns |
|---------|-----------|------------|------------|
| f=1     | 2.98 A, small electric arc | 2.79 A, electric arc < 4 mm | 2.63 A, electric arc 4 mm |
| f=5     | 2.88 A, smaller electric arc | 2.78 A, electric arc < 12 mm | 2.58 A, electric arc 12 mm |
| f=10    | 2.44 A    | 2.1 A, electric arc < 17 mm | 1.84 A, electric arc 17 mm |
| f=15    | 1.91      | 0.96 A, electric arc < 20 mm | 0.89 A, electric arc 20 mm |

![Figure 11](image.png)

Figure 11. The subroutine flowchart for the control of power transistors T1 and T2 (according to Figure 9)
Figure 12. The flowchart of the main program
The number of turns in the primary winding of the high voltage transformer (Figure 6) influences the generated voltage (12-16 kV AC voltage), the current absorbed from the low voltage power source (Icc), the length and shape of the arc. The experiments (Table 2) were performed without a high voltage diode.

A Fluke 80K-40 high voltage probe was used to measure the high voltage, which can measure the high voltage (maximum 40 kV DC or 28 kV AC). The probe is based on a resistance of the order of GΩ (approx 10 GΩ), for the high voltage divider and on the low side the internal resistance of the voltmeter (digital multimeter).

The internal resistance of the digital digital multimeter could be approximated to 10 MΩ. A high-performance Fluke 289 multimeter was used for the measurements, which was set to measure AC + DC voltage. Thus, the transformation ratio of the probe is 1000:1 (1kV is 1V measured with the digital multimeter). If it consider the high voltage resistance as Rm and the internal resistance of the digital voltmeter Rv = 10 MΩ (the two resistors being connected in series to form a resistive divider), if Uv is the voltage drop across the resistor Rv, and Um high voltage, then:

\[ U_v = \frac{R_v}{R_m + R_v} \cdot U_m \]  

(1)

The high voltage \( U_m \) can be determined by the relation:

\[ U_m = \frac{R_m + R_v}{R_v} \cdot U_v \]  

(2)

with transformation ratio:

\[ k = \frac{R_m + R_v}{R_v} \]  

(3)

In the next period of time (probably years) due to the COVID 19 pandemic, it is very likely that more people will no longer work in the same room for long periods of time (e.g. > 2 h). In the empty room it can be disinfected using ozone. Knowing the positive properties of anions on human health, anion generators can be used in rooms where there are people (during working hours).

This assembly, formed from the two generators (ozone and anions) is proposed to be used in classrooms, in administration, at multinational companies, in general, where several people work in rooms. It is known that SARS-CoV-2 virus is most easily transmitted through the air. Starting from the fact that ozone can be used as a disinfectant for rooms and surfaces, and knowing that, above a certain dose it is irritating to human airways, it is proposed to operate the assembly in Figure 6 in ozone generator mode when they are not people in the room, respectively the operation of the assembly from Figure 6 in anion generator mode when there are people in the room. After using ozone, the rooms must be natural ventilated for several dozens of minutes.

The main program, for the alternating operation of the ozone and anion generators from Figure 6, is proposed in Figure 12. The time intervals have been adapted according to the real hours of courses/laboratories/seminaries in a faculty, which can take place in the morning (8 AM - 12 AM) and in the evening (4 PM - 8 PM). During this period the anion generator works (K2 and K3 locked, Figure 6). Outside this interval, when there are no people in the room, the ozone generator is used (K1 and K3 locked, Figure 6). The ozone concentration is measured permanently (through Sn1, Figure 6), and if it is higher than the established one, the inverter in Figure 6 is disconnected (K1 and K2 triggered). If a decrease in air quality is detected (through Sn2, Figure 6), the anion generator can be started outside the preset program (e.g. at night).

6. Conclusions
Ozone can be used as disinfectant for rooms, objects and surfaces have been scientifically proven. At the same time, the use of anions has beneficial effects on human health.

The article presented generator which can be used on enclosed space that produce, in turn, ozone (when there are no people in the room), respectively anions (when there are people in the room).

The following conclusions can be made:
- Environmental surfaces and enclosed spaces may be contaminated with viruses (e.g., SARS-CoV-2) and contribute to their transmission;
- Using the ozone generation could be a solution to spaces virus disinfection;
- Anions have a lot of health benefits and can be used indoors;
- The ozone and anions generators using high voltages are easy to design and experiments;
- The Arduino Nano board can be used in high voltage high frequency power supplies.

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