A novel method for disinfection and sterilization using charged ozone water mist

Helena He, Kenneth He
Princeton International School of Mathematics and Science

Introduction

The COVID-19 virus has caused a large-scale global outbreak and has become a major public health issue[1]. Although there are several vaccines, herd immunity will likely take a long time to establish, and it is not clear whether the existing vaccines are completely effective against evolved versions of the virus. The COVID-19 virus as well as other respiratory viruses can be spread through coughing, sneezing, skin contact, etc., and can enter the human body from the eyes, nasal cavity, and oral cavity. Furthermore, such viruses can be excreted through feces, urine, and sweat. This is supported by a study, in which viral RNA was detected on almost all test surfaces (door handles, light switches, bed and handrails, windows, toilets, washbasins) in the isolation room of a COVID-19 patient[3].

Still, wearing a mask and keeping a certain distance are the most effective ways to prevent the spread of the COVID-19 virus[1]. But in many cases, people cannot wear masks such as when eating, drinking, singing, and exercising. Although there are various disinfectants that can cleanse the objects[4], the chemical agents have limitations, and some residues produced are harmful to the human body. Additionally, there are not many effective methods for killing airborne viruses; equipment such as high-power UV lamps are ineffective in places where the ultraviolet rays cannot reach.

Thus, because the effectiveness of air filtering viruses is affected by the size of the room and the power of the purifier, ozone disinfection may be the best option. As a gas, it can reach all areas of the room, being more effective than liquid spray[5]. Moreover, the process of the interaction between viruses and ozone has been studied extensively [6-9]. In another study, researchers found that after 30 seconds of exposure to ozone, 99% of the viruses are rendered inactive[6]. Yet, there are problems with using ozone as well. The use of ozone will corrode certain materials such as rubber and can be toxic to the human body in high concentrations. The U.S. Occupational Safety and Health Administration (OSHA) has set 0.1 ppm (8 hours) or 0.3 ppm (15 minutes) as the maximum amount of ozone for human safety exposure[10], and generally, people are allowed to enter the room after 24 hours of ozone disinfection. This greatly limits its use.

Therefore, the purpose of the research is to find a new method of disinfection and sterilization using safe levels of ozone. This method should not use any drugs or require complicated devices and expensive materials. It should be small in size, affordable, and easy to use. Additionally, this method can effectively kill germs and viruses carried on the surface of the human body, objects, and air, and can potentially be used to kill viruses and bacteria in the respiratory tract.

Principle

I envision an aerosol capable of the disinfection of the air, objects, and [potentially] body. The mist is produced using an ultrasonic mister. In order to have any effect on bacteria and germs, this mist has several features, which include:

1. The water particles in the mist carry high-voltage static electricity, which facilitates the absorption of airborne pollutants, dust, viruses, or germs.
2. There is dissolved ozone in the mist particles, which can quickly kill the adsorbed viruses or germs.
3. As the water particles evaporate, the dissolved ozone completely decomposes into oxygen, which can increase the oxygen concentration in the air without generating ozone harmful to the human body. Furthermore, the mist can increase the air humidity similar to other humidifiers.

4. If two mists with different polarities of static electricity are used, they will attract each other and produce a continuous micro-discharge in the air. Similar to thunderstorms, there will be a large number of negative ions generated, which will enhance the efficiency of the disinfection process.
5. Upon spraying this mist on objects or the skin with the opposite polarity, the water particles will rapidly release charges and deposit on the surface of the object or skin, forming a water film. Continuous discharge and high concentration of ozone in the water film can then kill viruses or germs on the surfaces.
6. This mist can be safely used for the disinfection of the face, hands, and respiratory tract. but this needs IRB approval.

The above assumptions are based on a few concepts. First, pulsed electric field sterilization technology similar to food processing utilizes a similar method[11]. The charged mist particles can discharge in the air, on the surface of objects or human skin with electric field strength (10-50kV/cm), pulse width (0-100μs), and pulse frequency (0-2000Hz). This will destroy the microbial cell membranes and membrane protein structures via electric pulse. Second, ozonated water is widely used to reduce viral infectivity through lipid peroxidation and damage to lipid envelope and protein shell[12-17]. Ozonated water can not only be used for wound disinfection or oral disinfection, but it is especially effective against viruses such as Epstein-Barr virus, papillomavirus, and HIV[18].

How The Prototype Works

1. The ozone generator passes ozone-containing air into the pure/distilled water in the water reservoir. At the same time, the undissolved ozone and air above the water are extracted and sent back to the ozone generator. This cycle repeatedly circulates and replenishes air regularly to gradually increase the ozone concentration in the water.
2. The humidifier is specially designed to prevent the ozone above the water tank from being emitted into the surrounding air with the mist. This ensures that the ozone concentration in the air is within a safe range.
3. The mister uses a high-frequency oscillation (1.7-2.4MHz) to generate a large amount of water mist. There will then be a fan that blows the mist out of the humidifier.
4. A high-voltage generator module is used to transform the low voltage from the battery into a positive and negative DC high voltage (from 3kV to 15kV).
5. The negative high-voltage output end of the high-voltage module is in contact with the ozonated water in the water reservoir. Thus, the mist particles blown out of the water tank all carry a negative electrostatic charge of no less than 3kV.
6. The positive high-voltage output end of the high-voltage module is in contact with the ozonated water in another water reservoir (in a different humidifier). The mist particles blown out of the water tank all carry a positive electrostatic charge of no less than 3kV, thereby obtaining two differently charged mists.
7. When the two charged mists (with no less than +/-8kV electrostatic charge) come into contact, the small discharges will eliminate any germs in the ambient air.
8. Objects can be disinfected via contact with positive static electricity not less than 3kV, and then by applying the mist (negative static electricity) to kill bacteria or viruses on the surface of the object. This process also applies to cleansing human skin.

Prototype

I plan to purchase an [corona] ozone generator, ultrasonic mister, high-voltage generator modules, a standard humidifier (for a base), and other components. I will also need ozone detectors (gaseous and aqueous), general-purpose electric meters, and other equipment. I will then assemble two prototypes that produce charged mists with different polarities. I will design the prototype according to Figure 1, a schematic diagram of the device. In the figure, “1” is a water tank with an ultrasonic mister. “2” is the mister itself. “3” is a seal that prevents gaseous ozone from escaping. “4” is the corona ozone generator. “5” is the pipe that intakes undissolved (gaseous) ozone from the water reservoir (“recycling” undissolved ozone). “6” is the ozone outlet pipe (into the water reservoir). “7” is a high-voltage electrostatic generator used to negatively charge the water. “8” is the negative high voltage output wire of the electrostatic generator. “9” is the positive high voltage output wire of the electrostatic generator. “10” is a conductive component in the water tank of the atomizer which is connected to the negative high voltage output electrode of the electrostatic generator through a wire.

Figure 2 is a photo of the prototype that I constructed. The cylindrical humidifier in the middle of the photo is the component that produces the mist via an ultrasonic mister. To the left of the humidifier are the ozone generator and air pump. To the right of the atomizer is a high-voltage electrostatic generator. The generator’s [negative] high-voltage output electrode is connected to the water reservoir through a wire. The black conductive film on the surface of the generator will positively charge objects via contact (i.e., When the conductive film is touched by hand, the human body will be charged with positive high voltage static electricity).

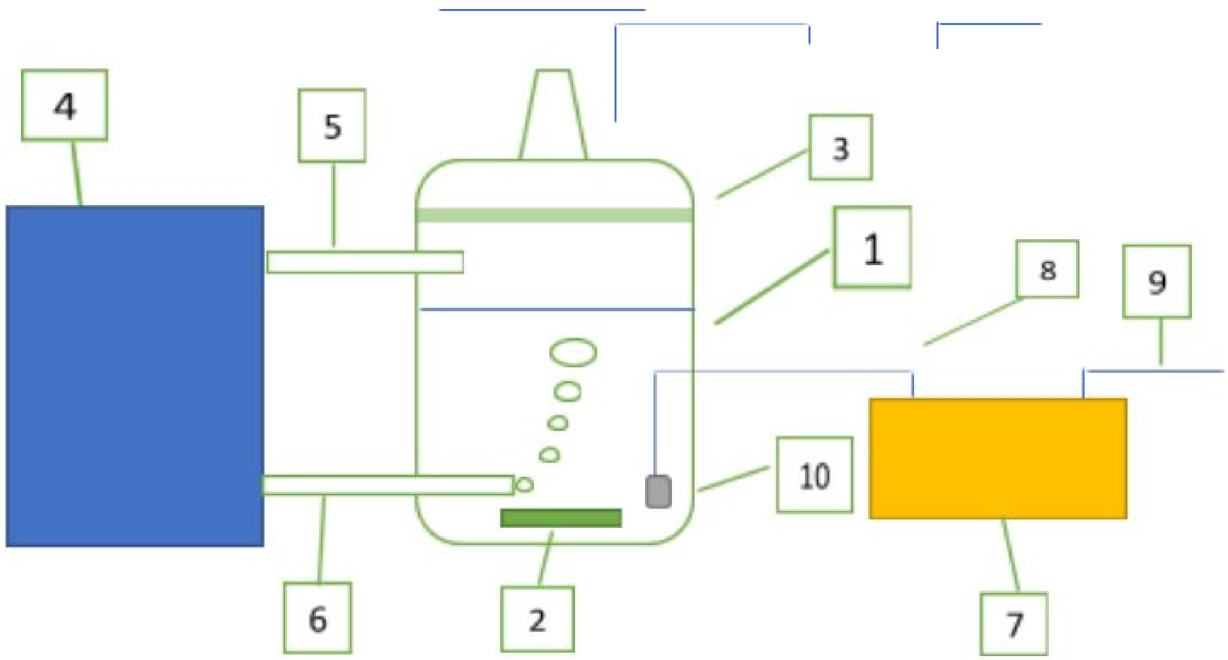

Figure 1. Schematic Diagram of Prototype

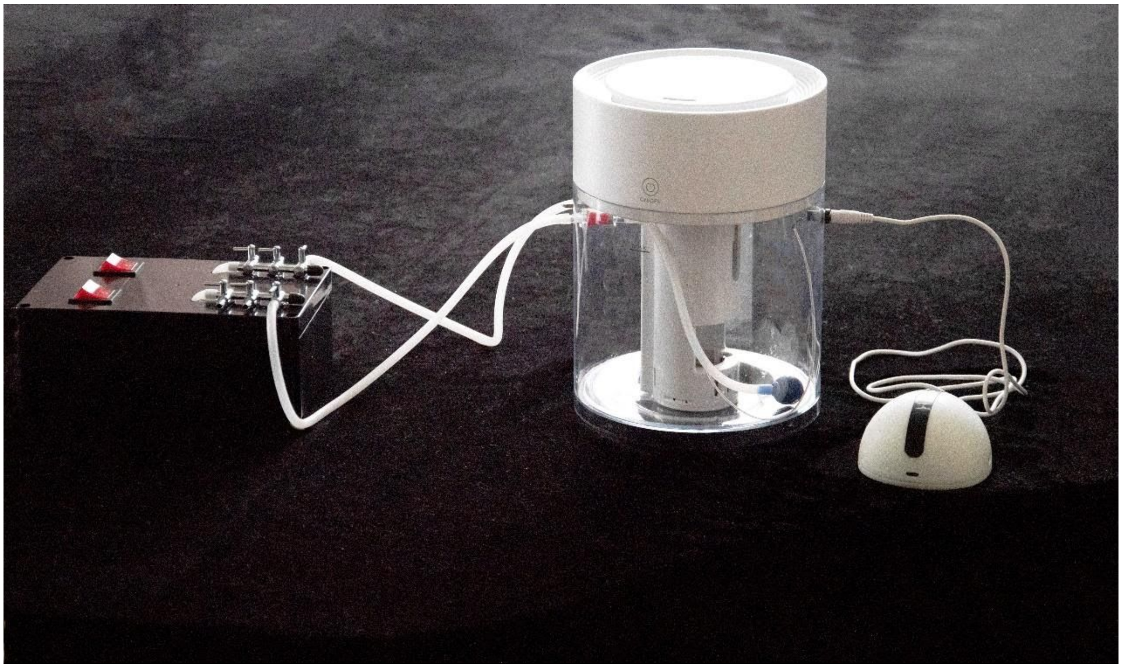

Figure 2. Photo of Prototype

Experimental test

Before using the prototype, I used an ozone detector (Gravity: I2C Ozone Sensor and Arduino Romeo V1.3 analog circuit) to monitor the ozone concentration in a 5 by 5 by 3 m3 room (room temperature 25oC, humidity 55%). After turning on the prototype for 10, 20, 30, 60 minutes, and 12 hours respectively, detect and record the indoor ozone concentration (control value). I tested other air quality-related parameters (PM2.5, PM10, TVOC, HCHO, CO, and CO2) using an HTO-132 Air Quality Detector (Hytop Innovation and Technology Co., Ltd) to monitor these parameters in a 5 by 5 by 3 m3 room. I recorded the values at times 10, 20, 30, 60, and 120 minutes.

To test the ozone levels in the water, I turned on the device for 1, 1.5, 2.5, 4, 6, 8, 10, 15, 20, and 300 minutes respectively, then used a test tube to take out 15ml of ozonated water from the water tank. Then, I would add an ozone test reagent and let it stand for 2 minutes. Subsequently, I would compare the color of the water sample card comparison to determine the ozone concentration in the water.

To test the efficiency of my prototype on bacteria on the surface of the hand, I commissioned a professional facility (China National Research Institute of Food and Fermentation Industries CO., LTD.) to conduct the tests using my prototype. 15 volunteers participated in the test. The test used the conventional method of detecting the total number of colonies of bacteria: the left and right hands of the volunteers are sampled, diluted, cultured, and observed to obtain the difference between the total number of colonies in the two hands. Before sampling, the volunteers repeatedly rubbed their hands on a dirty cloth, and then rubbed their hands for 2 minutes to ensure that the number of bacteria on either hand were in roughly equal concentrations. The left hand was sprayed with an ordinary humidifier and then sampled using a sterile cotton swab. The right hand was sprayed with a charged water mist from the prototype for 3 minutes before sampling. Before spraying, the volunteer needs to place his/her left hand on the black conductive film of the high-voltage electrostatic generator (see Figure 2) to let the volunteers have a positive electrostatic charge on their right hands. When the negatively charged ozone water mist is sprayed on the right palm, a continuous micro-discharge is generated between the water mist particles and the palm.

To test the efficacy of the mist on the flu virus(H1N1), I commissioned a professional organization to perform the following tests using my prototype: H1N1 virus was placed on a 10mm by 10mm stainless steel slide; the slide was then connected to the positive and high voltage (+8KV) output electrode of the high voltage electrostatic generator, and negative high voltage (-8KV) static electricity was sprayed on the surface of the slide. The virus inactivation rate was measured when the time was 5, 10, 15, and 20 minutes, respectively. (Each inactivation rate data is the average of three tests.)

Results

1. Ozone in air (Figure 3):

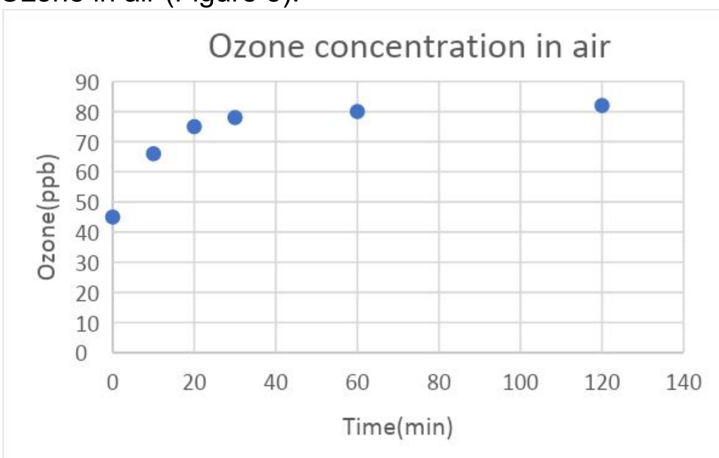

Fig. 3. Ozone Concentration in a Room Over Time

2. Other air quality related parameters (Figure 4)

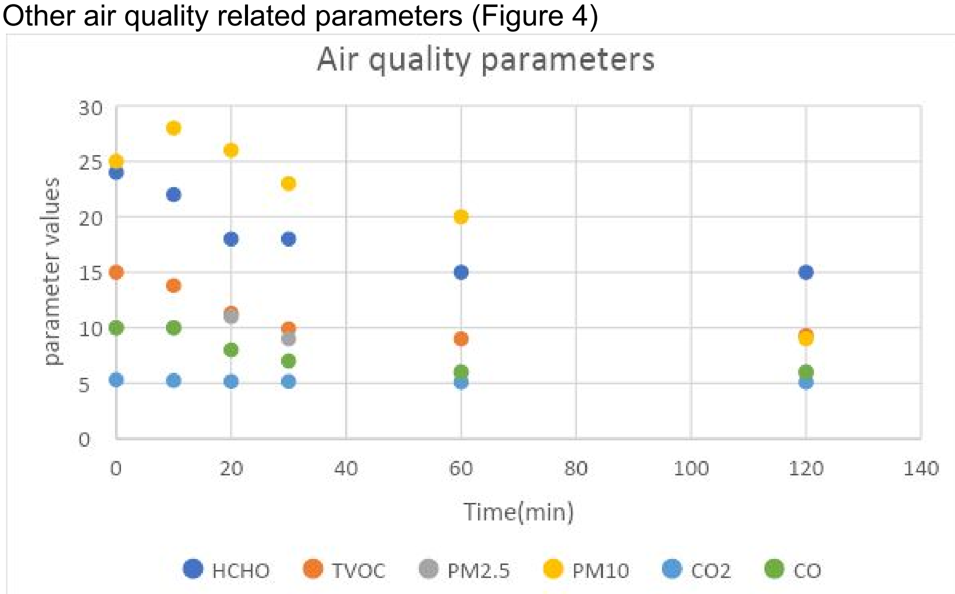

Fig. 4. Air Quality in a Room Over Time

In Figure 4, the units of parameters are: HCHO (mg/M^3), TVOC (10mg/M^3), PM2.5(ug/M^3), PM10(ug/M^3), CO (ppm), CO_2 (100ppm).

3. Ozone in pure water (Figure 5)

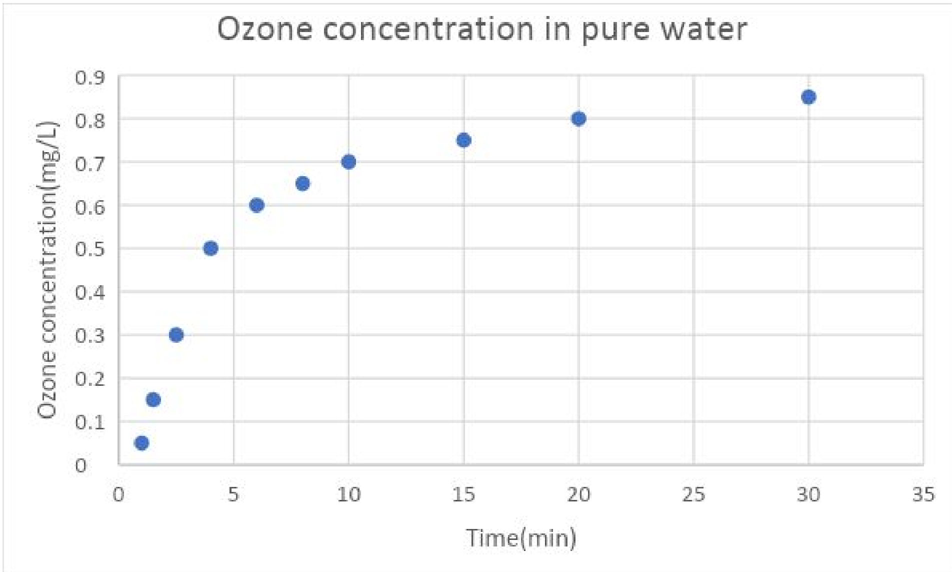

Fig. 5. Ozone Concentration in Pure Water

4. Bacteria Colonies in the Palm's Surface (Table 1):

Number	Comparison group	Test group	Sterilization rate
1	18000	1600	0.911111111
2	140000	28000	0.8
3	210000	8100	0.961428571
4	25000	460	0.9816
5	23000	790	0.965652174
6	85000	3100	0.963529412
7	25000	3100	0.876
8	16000	1400	0.9125
9	160000	26000	0.8375
10	150000	24000	0.84
11	1300	120	0.907692308
12	180	20	0.888888889
13	730	35	0.952054795
14	1500	45	0.97
15	2000	170	0.915
Average			91.20%

Table 1. Bacteria Colony Count

5. H1N1 on object surface (Table 2):

Time(min)	logarithm of inactivation	Average inactivation rate
5	1.56	95%
10	2.23	99%
15	3.05	99.90%
20	3.55	99.95%
25	>4	>99.99%

Table 2. Average Inactivation Rates at Different Times

Discussion

1. From Figure 1 and 2, we can see the water tank of the ultrasonic atomizer is sealed, and almost no ozone can escape into the air. It can be seen from Figure 3 that in the first 30 minutes of the prototype spraying, the ozone concentration in the indoor air increased rapidly, but then gradually stabilized. This is because although a very small amount of ozone leaks from the prototype, the ozone that escaped earlier will also be decomposed into oxygen, so it will gradually reach equilibrium over time. We also see the ozone value was always below 100PPB. According to American standards, it is safe to work for 8 hours at an ozone concentration of 100PPM. According to the regulations of the International Ozone Association, at a concentration of 100PPM, 10 hours of work are allowed. According to Chinese standards, as long as the ozone concentration is lower than 150PPB, it is safe. Therefore, the use of this prototype for indoor spray disinfection is in line with safety standards.
2. Figure 4 shows that the concentration of various indoor air pollutants gradually decreases with the spray time of the prototype. In particular, particulate matter (PM10) and gaseous pollutants (HCHO and TVOC) dropped significantly after 1 hour of spraying. This shows that the dust reduction effect of the aerosol and the ability to adsorb gaseous pollutants are stronger. This is related to the static electricity charged by the aerosol particles.
   Studies[21] have shown that if suspended particles have 50 elementary charges, the collision efficiency between suspended particles and water droplets will increase by 30 times. This may be because after the suspended particles are sufficiently charged, they will cause image charges on the falling water droplets, making it easier to collide. Compared with neutral, uncharged molecular clusters, charged molecular clusters are able to attract surrounding air molecules and will grow to a certain size at a faster rate. These charged molecular clusters come from the evaporation and condensation of water molecules. Once nucleated, these charged molecular clusters will be more stable. The simulation results show that if the ionization rate is increased by 25%, the concentration of particles with a particle size in the range of 3-10nm will increase by 7-9% after 8 hours of nucleation.
   The new technology proposed is to charge the so-called raindrops to replace particulate matter and gaseous molecules. The purification effect is the same.
3. It can be seen from Figure 5 that the ozone concentration of the pure water in the prototype tank can rapidly increase to 0.6 mg/L within 5 molecules. Then maintain the concentration not lower than this value for a long time, and the efficiency is close to 100%. If the traditional bubbling method is used to dissolve ozone, a pool of no less than

4-5 meters in height is required, and its efficiency is only about 20%. If the jet method (Venturi method) or turbo pump technology is used, the equipment structure is complicated, the cost is high, and the noise is large. If electrolysis is used, special materials are required[22]. The prototype design can ensure that ozone water of sufficient concentration can be quickly produced without the need for huge and complex equipment or expensive materials.

4. It can be seen from Table 1 that the charged ozone water mist can kill microorganisms in a short time. The sterilization rate exceeds 90%. According to the empirical formula of the U.S. Environmental Protection Agency (EPA) and the Safety and Health Administration (OSHA)[23]: Only when CT ≥1.6 can effectively kill microorganisms in water, where C is the concentration of ozone in water (mg/L), T It is the action time (min). From Table 1, the ozone concentration is only 0.3mg/L when the prototype is turned on for 3 minutes, and the CT value is only 0.9 under the condition of palm spray for 3 minutes, which is far below the minimum value of 1.6. Thus, in addition to ozone, the key factor for the prototype to be sterilized in a short period of time is the continuous micro-discharge between the charged water mist particles and the palm of the hand, causing microorganisms to be continuously shocked.
5. Table 2 shows that charged ozone water mist can inactivate influenza viruses in a short time. A research[24] has shown that when the ozone content is 27.73 mg/L, the SARS virus can be completely inactivated after 4 minutes of action; when the ozone content is 17.82 mg/L, the effects of 4 minutes and 4.86 mg/L can be used for 10 minutes, both of which can make the SARS virus inactivation rate. Up to 100%. Another document[25] shows that when the ozone concentration is higher than 60.3mg/m3, the surface coronavirus can be completely killed when the action time exceeds 15 minutes. The highest ozone water concentration used in this experiment does not exceed 1.0 mg/L, which is much lower than the ozone water concentration used in the above literature, but it can still completely inactivate the N1H1 virus in about 20 minutes. The electric water mist particles discharge to the slide and produce a sustained electric shock to the virus.
6. Although the charged voltage of the water mist particles is greater than 3kV, the discharge pulse current is not higher than 0.01mA, power is not higher than 0.05W, even if people are exposed to the charged water mist, there is no harm.
7. Ozone dissolved in water is very safe. Ozonated saline that can directly enter the human body is 0.9% saline with 90 mg/L ozone added[18]. The ozone concentration in the charged water mist is generally only 1-3mg/L, even if it touches the skin or is inhaled into the respiratory tract, it is absolutely safe. When the water evaporates, the ozone in the water mist will decompose into oxygen without volatilizing into the air.

Conclusions

The charged ozone water mist produced by the ultrasonic generator and the high-voltage electrostatic generator can kill the bacteria and viruses on the skin or the surface of the object in a short time (3-20 minutes). Its sterilization rate and inactivation rate reach 90% and 99% respectively. In addition to a specially designed device that can quickly generate and maintain an ozone concentration of not less than 0.6mg/L, the continuous micro-discharge between negatively charged water mist particles and positively charged skin or objects will cause bacteria or viruses. The electric shock effect significantly improves the disinfection and sterilization effect of the ozone water itself and shortens the action time. In addition, the charged ozone water mist can effectively purify the indoor air. The next step is to study the effect of water mist on the killing of microorganisms and viruses in the air, especially the research on the inactivation of human respiratory viruses.

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