Application of dielectric surface barrier discharge for food storage

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Abstract

Ozone (O_3) is a powerful oxidizer and has much higher disinfection potential than chlorine and other disinfectants. Ozone finds its application mainly in water treatment and air purification Dielectric barrier discharge (DBD) method has proved to be the best method to produce ozone. Dried air or oxygen is forced to pass through a 1-2 mm gap. The aim of this study was to show that disinfection system using ozone generated by dielectric barrier discharge (DBD) is an effective alternative to be used in food industry and ensures a safe quality of air for optimum preservation of fruits and vegetables. The DBDs are specific kind of discharges because one (or sometimes both electrodes) is covered by a dielectric material, thereby preventing the discharge to move towards electrical breakdown. A succession of micro-discharges occurs rapidly; their "lifetime" is in the range of a few nanoseconds. One of their most important applications is the production of ozone for air treatment, used mainly in the area of food industry, for extending the storage life of foods. After the achievement of a surface DBD reactor of cylindrical shape and its electrical characterization, it was then used as an ozone generator for air disinfection. Obtained results have shown that this reactor used as an ozone generator is effective for disinfection of air by removing viruses, bacteria and pathogens, causing the slowdown of the ripening process of fruits and vegetables.

Keywords

Dielectric Barrier Discharge; High voltage, Ozone; Electrodes; Plasma; Ozone generator

Introduction

Dielectric barrier discharge (DBD) plasma reactor enables the generation of plasma-active species at atmospheric pressure without expensive vacuum systems [1]. Active species can include ultraviolet or visible photons, charged particles, including electrons, ions and free radicals, and highly reactive neutral species, such as reactive atoms (oxygen, fluorine, ozone, nitrogen oxides, etc), exited states atoms, and reactive molecular fragments [2]. Emission of UV-light and generation of radicals and charged particles contribute for destruction of microorganisms in plasmas.

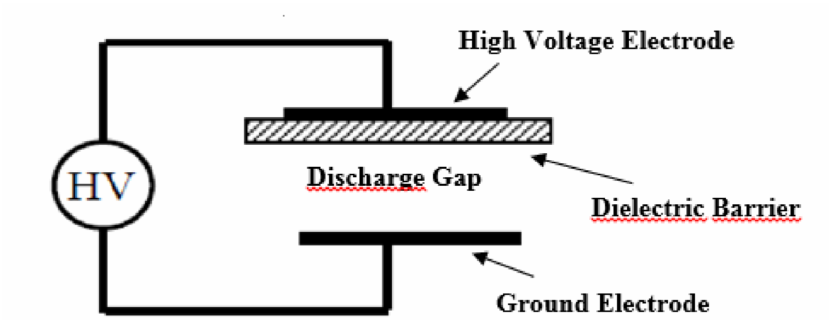

Figure 1. *Classical configuration of DBD* discharge

Ozone produced in plasma region is a powerful oxidizer that could destroy microorganisms effectively [3]. Ozone concentration in nature varies between 0.01 ppm to 0.05 ppm, depending on season and geographic location. High voltage ozone generators produce ozone/gas mixture, which contains 1 % to 3 % ozone when using dry air, and from 3 % to 6 % ozone when high purity oxygen is used as a feed gas [4].

The dielectric barrier discharge (DBD) has been known more than a century and the early experiences on such discharges were reported by Siemens in 1857 [5,6]. Their field of application is very large: ozone generation, waste gas treatment, activation and surface treatment, CO2 laser, excimer lamps, plasma screens and involves many industrial fields: water treatment, environment, electronics, textile, packaging, automotive [7-9]. One of their largest applications is the generation of ozone for treatment of water and disinfection of air.

This type of electrical discharge is a "cold non-equilibrium" plasma source, characterized by the presence of at least one dielectric layer between two metal electrodes (Figure 1). The presence of insulation can reduce energy flowing through the discharge channel and avoid the transition to the arc; however this requires the use of an alternative electric excitation.

The aim of this paper is to show that the ozone generated by a dielectric barrier discharge can be considered as an advantageous solution for air disinfection and storage of the food in the food industry.

Operating principle of DBD discharge

Under the action of a sufficiently high electric field applied to the gas space (a distance of the order of a few millimetres), an electron avalanche may be initiated in the gas and establish a conductive channel is called micro-discharge (Figure.2.a).

This conduction channel leads to the appearance of a space charge. The accumulation of charges in the vicinity or on the dielectric leads to a rapid decrease in the potential difference of the gas space. The discharge stops, micro-discharges are initiated in new places: the current pulse is generated (Figure.2.b).

The change of polarity (Figure.2.c), the charges previously deposited on the dielectric permit restrict of micro-discharges in a lower than at the first alternating field [10].

Materials and methods

A surface DBD reactor of cylindrical shape was achieved. The dielectric barrier is constituted by a glass tube having a diameter of 50 mm and a thickness of 2 mm. The electrodes are a fine strip of adhesive aluminum bonded directly on the outer surface of the glass tube (Figure 3). The other metal electrode, a stainless steel mesh was placed inside the glass tube in contact with it (Figure 4). When a high voltage is applied to these electrodes, bluish color plasma is formed on the surface of the tube in contact with the mesh electrode and is distributed homogeneously along the tube (Figure 5).

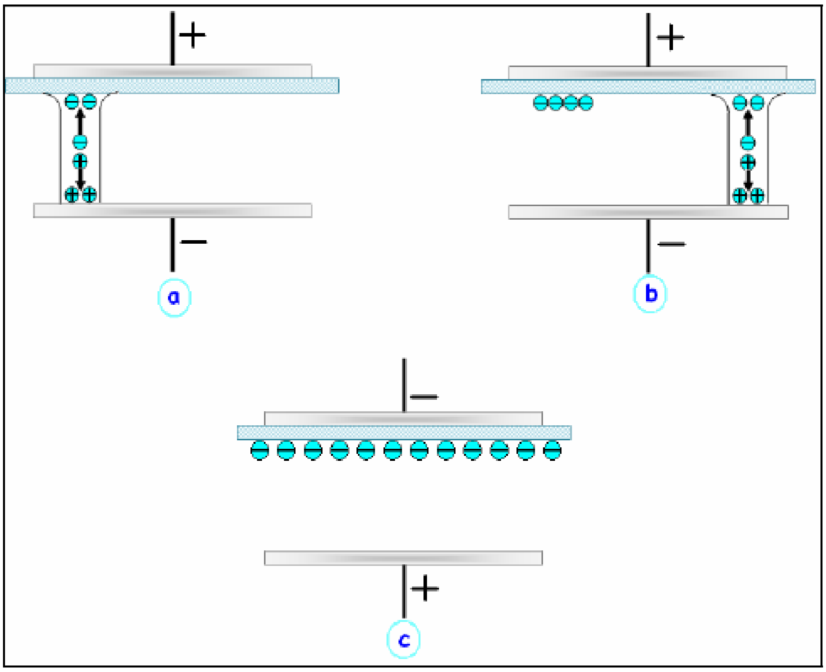

Figure 2. *Discharge mechanism OF DBD*

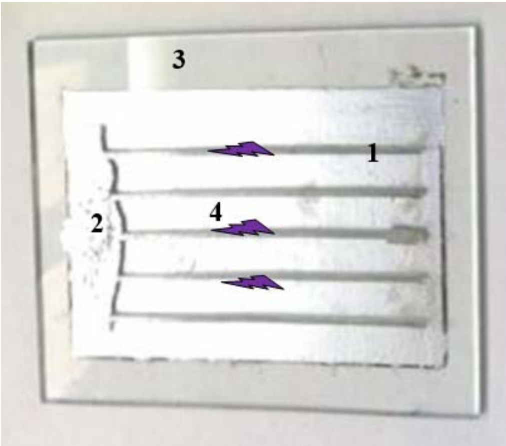

Figure 3. *Schematic description of the DBD reactor the surface 1. High voltage Electrode 2. Ground Electrode 3. Glass tube (dielectrique barrier) 4. DBD Discharge*

Figure 4. *Dielectric barrier discharge surface (photo of day)*

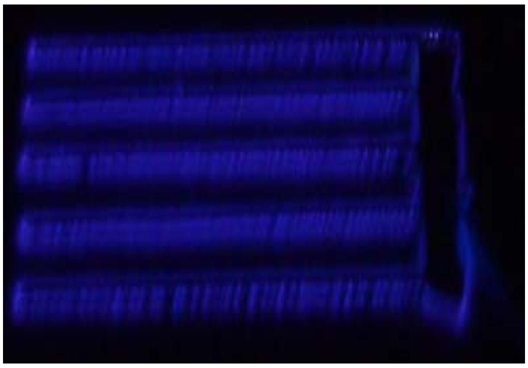

Figure 5. *Dielectric barrier discharge occurring in the reactor (night photo)*

An experimental study was conducted including two aspects:

-Electrical characterization of the plasma reactor.

-Using the reactor as ozone generator for air treatment.

Experimental procedure and electrical characterization

This part of the study was to make an experimental study for the electrical characterization of the reactor, for calculating its power by measuring the applied voltage and the current through the discharge. The circuit assembly used is shown schematically in Figure 6.

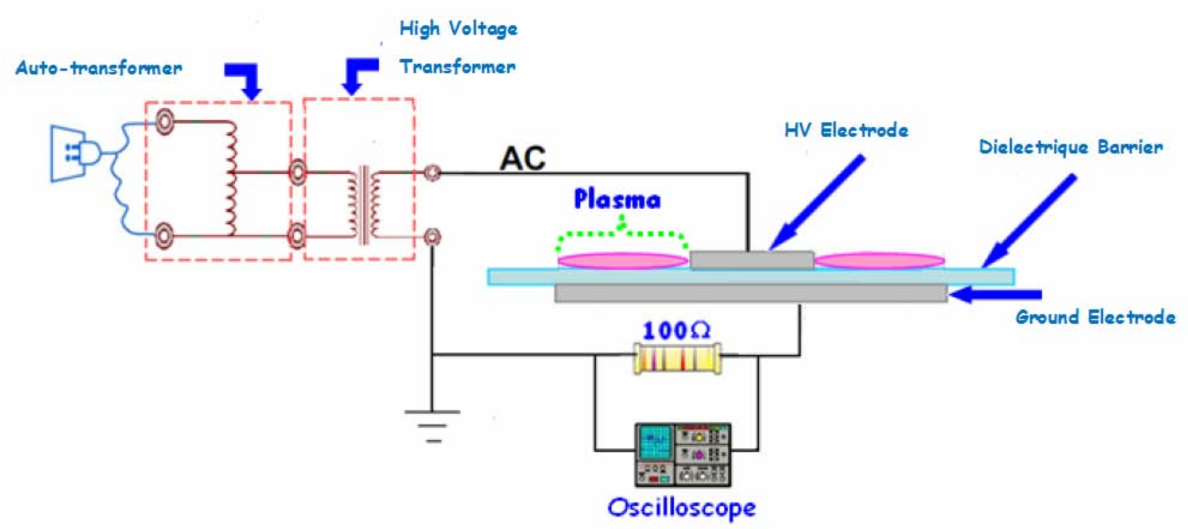

Figure 6. *Schematic representation of the experimental setup for studying the DBD*

An electrostatic voltmeter and an oscilloscope where used to measure the applied high voltage and the current. The high voltage was delivered by a power supply of voltage 6 kV, current 30 mA and frequency 10 kHz. A 100 Ω resistor was placed in series with the circuit, whose voltage drop is visualized by the oscilloscope to measure the current generated by the DBD (Figure 7).

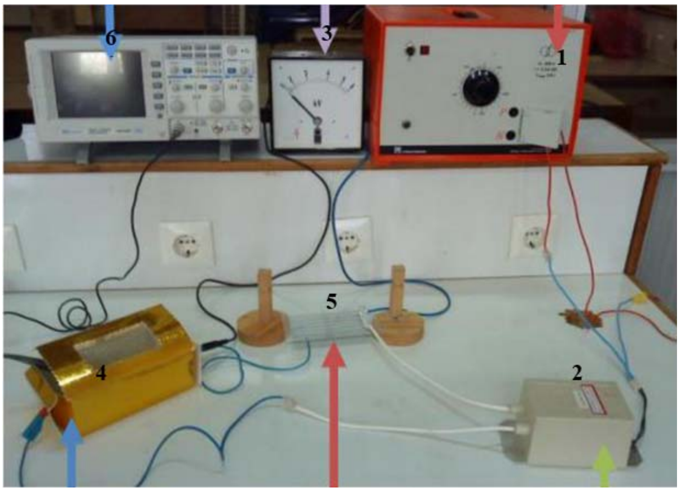

Figure 7. *The experimental device for measuring the current 1. Variac; 2. HV Transformer, 3. Electrostatic voltmeter; 4. Resistance; 5. DBD reactor; 6. Scope*

Results and discussion

The measured values from the current diagram are the peak value of micro-discharges and the "glow" current amplitude; these parameters are shown in figure 8 on the diagram of the current registered by the oscilloscope. The power measured is the product of the "glow" current amplitude by the applied voltage. Obtained results for different values of voltage are shown in Table 1.

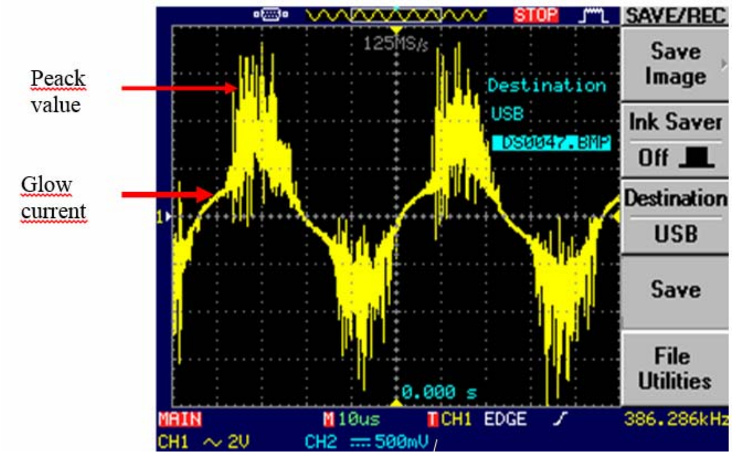

Figure 8. *Characteristic parameters of discharge current*

The current is made of series of pulses appear at each half-period, after turning off the voltage reaches its maximum value. This current waveform is typically a series of micro-discharges which occur in a dielectric barrier discharge.

These results provide a first approach to the study of the dielectric barrier discharge, and open the way for further work to optimize a cell for the treatment of air and water pollution control. However, these preliminary studies have used, for the first time in the laboratory.

Table 1. Current values measured as function of voltage

U (kV)	**Peak values of micro-discharges (mA)**		**« glow » Amplitude (mA)**	**Power (W)**
	Positives	**Negatives**		
2	8	8	8	16
3.5	16	14	14	49
4.5	22	19	18	81
5.5	26	22	22	121
6	28	26	23	138

It appears from these results that the DBD filamentary discharge starts from 2 kV, which is a rather low breakdown voltage compared to a volume DBD. Indeed, in the case of a surface discharge there is almost a micrometer intervals gas between the mesh electrode and the dielectric barrier, while this interval is of the order of millimeters in volume DBD. Micro-discharges reach high peak values, much greater than the "glow" current amplitude. Also, should be noted that for this reactor, having length of 25 cm and a diameter of 8 cm, consumed power varies from 16 to 138 Watts (Figure 9).

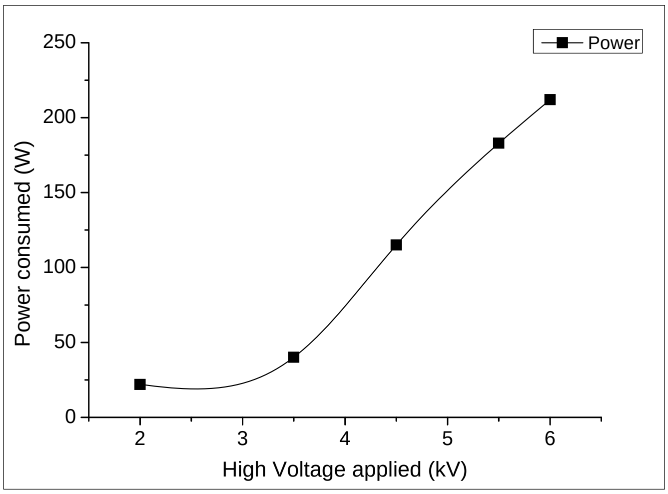

Figure 9. *Power consumed by reactor DBD*

Application of the reactor DBD surface for food storage

The reactor was then used as an ozone generator for disinfection of air in order to extend the shelf life of food products. The laboratory setup used is described in figure 10. The products to be stocked are put inside a glass enclosure; ventilation system allows the injection of ozone inside the enclosure (Figure 11).

Ozone is mainly used for the treatment of air and water, removing bacteria, viruses and unpleasant odors, but it must not exceed a certain limit amount which may produce the opposite effect. The recommended amount of ozone is approximately 20 ppm (parts per million) for effective conservation of food products [11].

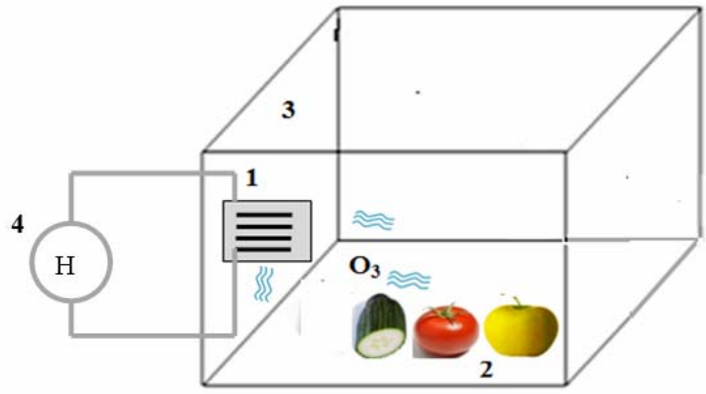

Figure 10. *Schematic description of the disinfection process 1 - Ozone generator, 2 - Foods to be processed; 3 – Enclosure of air treated, 4- power supply*

Figure 11. *Photography of enclosure of air traited (1) and enclosure control (2)*

Production of ozone is controlled by two main parameters:

-applied high voltage;

-application period of ozone generator.

The influence of these two factors was studied by setting one factor a constant value and varying the other. After switching on the generator for determined values of voltage and period application, the rate of ozone which decreases according to time was measured at time intervals of 2 minutes.

The rate of ozone depletion for different values of voltage is shown in Figure 12, and in Figure 13 for different values of period application. It follows from these results that the level of ozone is proportional to the voltage and period exposure and it is halved after nearly 30 minutes. The values of appropriate values of voltage and duration derived from these results that achieve a rate of 20 ppm is U = 2.5 kV and T= 8 s respectively.

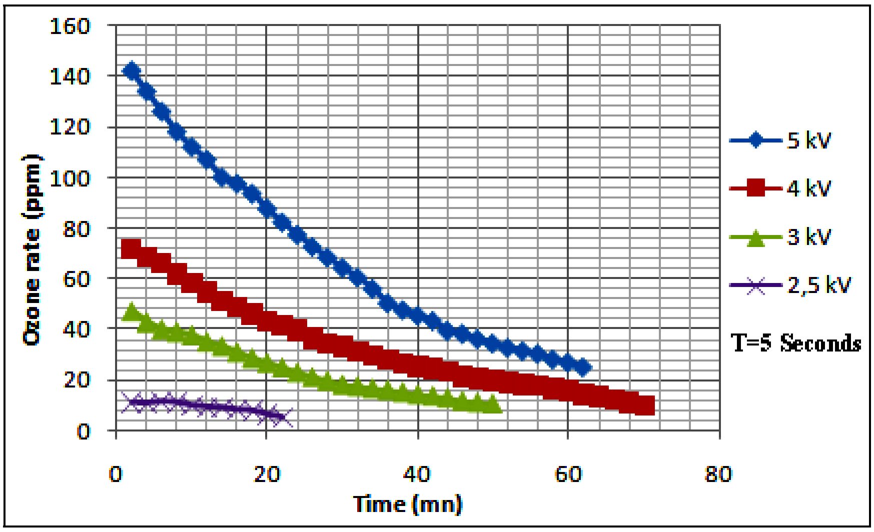

Figure 12. *Change in ozone levels according to the applied voltage*

A second enclosure of untreated “normal” air, within which identical food are placed, was used as an "indicator enclosure". The results were expressed in days of food preservation by taking photographs of the food put in the two enclosures. Obtained results are shown in the following figures, comparing the state of the products, after several days of storage (Figure 14, 15 and 16).

These results show clearly that food stored in the enclosure treated with ozone are resistant to contamination much more compared to products placed in the untreated enclosure, eliminating bacteria and slowing their development. Production of ozone by DBD reactor is an effective way to disinfect air and represents a well-adapted solution in the agro-food sector.

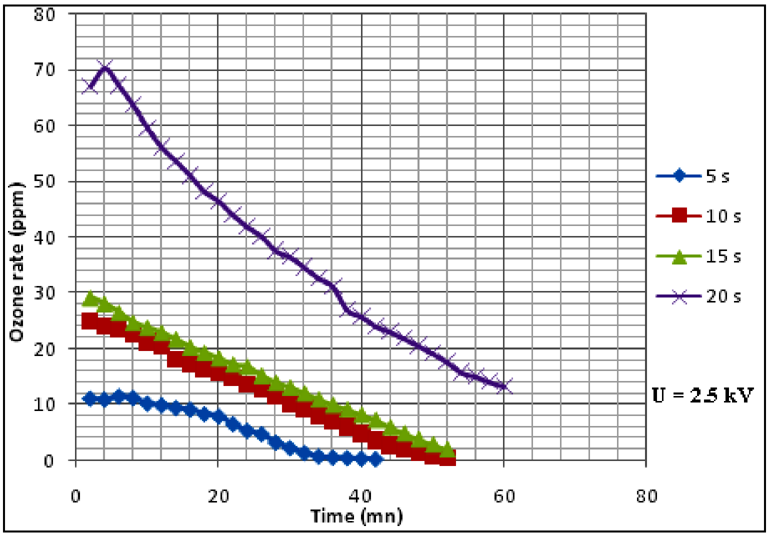

Figure 13. *Change in ozone levels according to the application period*

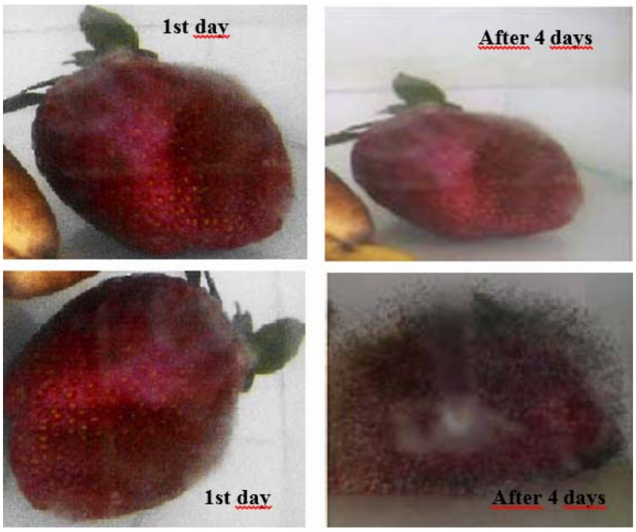

Figure 14. *Comparison between the states of the strawberry treated with ozone (up) and food products untreated (down)*

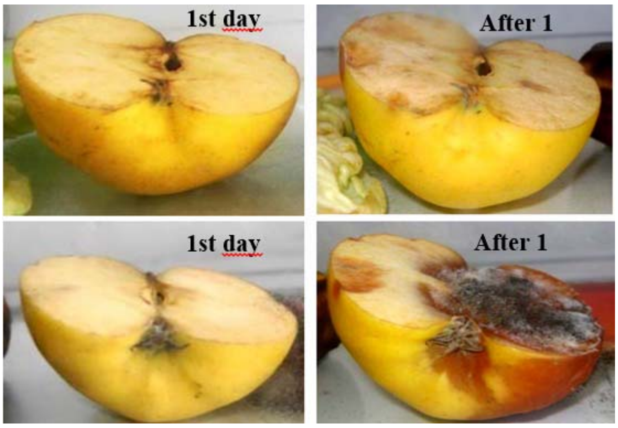

Figure 15. *Comparison between the states of the apple treated with ozone (up) and food products untreated (down)*

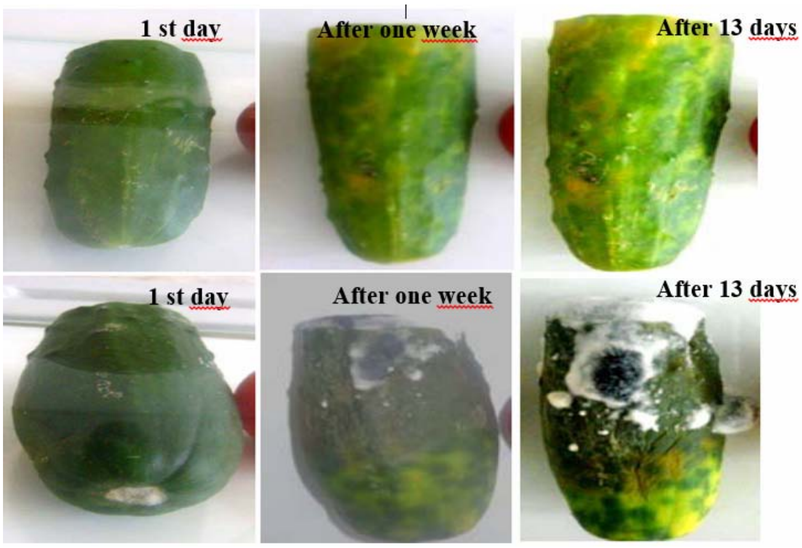

Figure 16. *Comparison between the states of the cucumber treated with ozone (up) and food products untreated (down)*

The application of this method based on a DBD discharge type for the air disinfection was effective. Indeed, the results showed that the disinfection of air by this method can extend the shelf life of food products. This method can be used very well in cold storage life of food products.

Production of ozone by dielectric barrier discharge is a cost effective method, which achieves high levels of ozone. Using the dielectric barrier discharge reactor as an ozone generator is effective for disinfection of air in agro-food industry for extending the shelf life of foods. The DBD which consists in a multitude of micro-discharges, enables the generation of ozone which is then pumped into the air, killing bacteria and viruses. The generation of ozone by a dielectric barrier discharge depends on the high voltage applied and the duration of this discharge. These two parameters are proportional to Ozone rate generated.

Conclusions

The results presented in this paper clearly show the effectiveness of ozone in the air disinfection and the extension of the shelf life of the food. Indeed, it has been proven through experiments performed on samples of fruits and vegetables, that the installation of a system of air disinfection by ozone for food storage provides an ambience of pure disinfected and a well oxygenated air.

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