CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

OZONE FOOD STORAGE SUPPLIED BY PHOTOVOLTAIC ENERGY

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Article history:
Received
12 June 2018
Accepted
15 December 2018

Keywords:
Photovoltaic system;
Inverter;
Food storage;
Ozone generator.

ABSTRACT

In Algeria and in several Third World countries, there are many isolated sites that are not yet connected to the conventional electrical grid. They face mostly problems such as food storage, which is a real constraint for rural residents. The purpose of this paper is to design and implement at a lower cost a system comprising a photovoltaic system supplying an ozone generator for the disinfection of a food storage room in an isolated site to increase the shelf life of the food products. An experimental study was conducted using several fruits and vegetables that were placed in an ozone treated room. A comparative study using a similar control untreated room has shown that such a system allows long-term storage with low energy consumption of nearly 16 W/m^2.

1.Introduction

In recent decades, various cultural, industrial and economic activities have led to increased electricity consumption, raising concerns about greenhouse gas emissions and the reliability of electricity supply. The photovoltaic (PV) system advantages include a long service life, reduced maintenance, ease of installation and no fuel consumption; the major disadvantage is the low production by cloudy weather

The geographical location of Algeria gives it a high solar potential and good exposure to solar energy. By receiving an average of 3000 hours/year of solar radiation, Algeria has the highest solar potential in the Mediterranean basin (169440 TWh / year) (Bey et al., 2016).

In addition, despite the government efforts to increase the electrification rate, some households in rural areas are deprived of electricity. The high cost of the investments needed to expand public networks as well as the limited needs of the remote areas concerned will continue to hinder their connection in the medium term. This is why photovoltaic systems in isolated sites are an interesting alternative (Korsaga et al., 2018).

On the other hand, these households are confronted with the problem of food storage of fruits and vegetables. Generally food storage is carried out in cold rooms at low temperature (below 10 °C) whose electrical operating power is relatively high (2000 W for a volume of 20 m^3), requiring thus a great amount of electrical energy. Therefore, because of the high cost for implementing the necessary equipment for cold rooms, such as air conditioning, accessories, etc.., the high electricity consumption and the precarious financial situation of third world countries, it is difficult to build cold rooms with its requested electrical energy in isolated sites.

This is why ozone treatment of non-air conditioned food storage rooms could be an effective and economical solution for the conservation of agri-food products.

One of the important usages of ozone in agriculture is the post-harvest treatment of harvested crops. Ozone can be applied to foods as a gas or as a dissolved form in water. The main purposes of ozone application at the postharvest stage are inactivation of bacterial growth (Sharma, et al., 2002; Achen & Yousef., 2001; Kim & Yousef.,2000; Kim & Yousef., 1999; Roya et al., 2016), prevention of fungal decay (Palou et al., 2002; Perez et al., 2002), destruction of pesticides and chemical residues (Hwang, et al., 2001; Ong et al., 1999), and control of storage pests (Mendez et al., 2003; Kells et al., 2001).

Ozone is increasingly used for the storage of fruits, vegetables, flowers, meat, fish, cheese, etc ... for strengthening the quality of conservation of the market, control of pathogens, molds, fungi, yeasts and other micro -organisms. In (Ewell et al., 1938; Pérez et al., 2002) it is stated that the shelf life of strawberries can be doubled if a dosage of 2-3 ppm (particles per million) of ozone is applied regularly for a few hours a day. Fruits and vegetables such as apples, potatoes, tomatoes and many more can be disinfected and kept longer thanks to ozone. In (Skog & Chu., 2001) it is indicated that the application of ozone at reduced concentrations in cold rooms on cucumbers, mushrooms, apples and pears for different temperatures can increase storage time.

Moreover, in (Brahami et al., 2015) a photovoltaic solar system is described for supplying an ozone generator, which has been used for water treatment. It has been shown that the optimization of the orientation angles of photovoltaic panels can increase the efficiency of the ozone water treatment system despite the climatic disturbances due mainly to the passage of clouds.

The aim of this work is twofold: to increase the storage time of food in rooms located in isolated sites that do not have air conditioning system using ozone disinfection, while ensuring an autonomous power supply by photovoltaic energy. Different fruits and vegetables were tested in a closed room treated with ozone.

2. Materials and methods

Figure 1 shows the overall experimental system used for analyzing food storage in an ozone treated atmosphere supplied by a PV power system. The experimental setup consists of two separate parts: the solar energy system and the ozonation system.

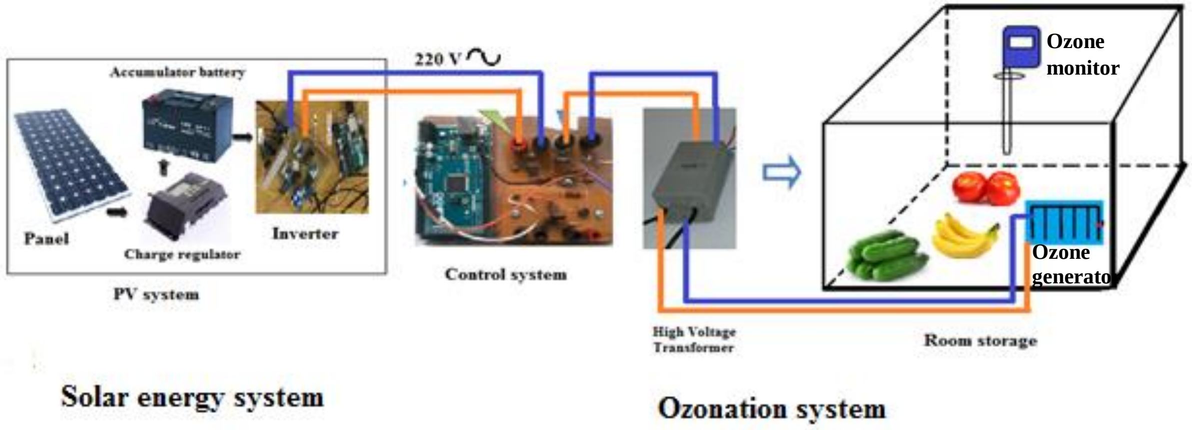
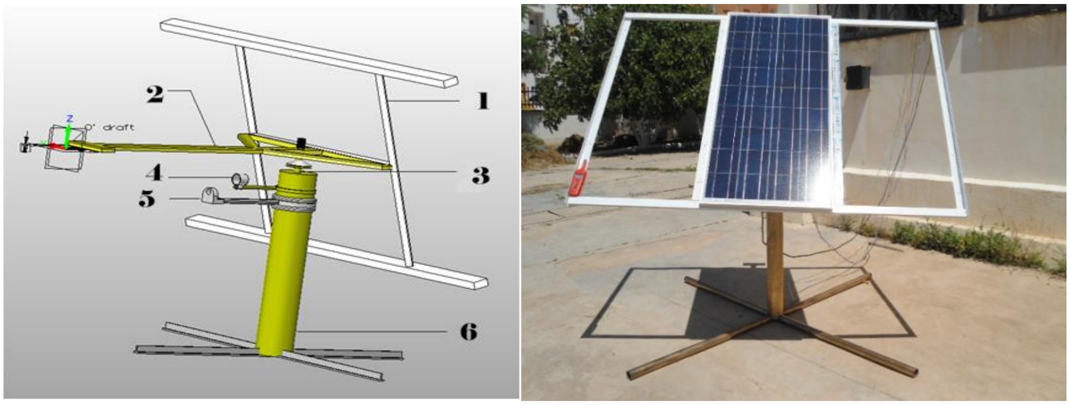


Figure 1. Schematic representation of the experimental setup

2.1. Solar energy System

As shown in (Fig.1), the solar energy system includes a photovoltaic generator producing a power of 135 W, a charge controller (12/24 V, 20 A) to keep the voltage constant at 12V, an 80 Ah storage battery used to store the energy and a single-phase inverter. In this work, the solar PV system was designed to allow the solar panel to undergo a horizontal and a vertical rotation movement to follow the sun and thus optimize the surface exposed to sunlight (Fig.2). Therefore, an optimal panel position can be determined corresponding to a high level of power generation. Preliminary experiments made it possible to define the ideal position of the panel which should be oriented towards the south (corresponding to zero east-west angle), with an incline south to north angle varying from β = 40° to β = 50° in Sidi Bel Abbes city, Algeria (Brahami et al., 2015).



(a)

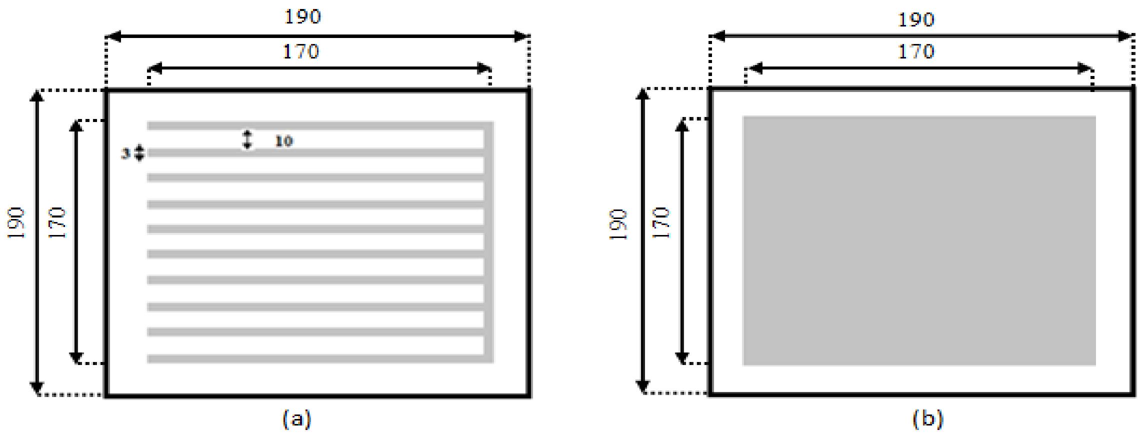
(b)

Figure 2. Photovoltaic system
a) General view of the mechanical structure of the PV panel
b) Photography of the PV panel
1. Framework supporting the PV panel, 2: Limit switch of south-north Axis; 3: East-west orientation Pulley; 4: Motor for East-west orientation; 5: Jack Support for north-south orientation; 6: Cylinder supporting the structure.

2.2. Ozonation process

The ozone treatment was carried out inside a metal enclosure of dimensions 2x1.2x1 m^3 inside which was placed an ozone generator fixed on the upper wall. An identical metal enclosure without ozone generator was used as a control room. A portable ozone monitor (O3 Technologies) was used to measure the ozone concentration in the treated room, in ppm.

The best method for generating ozone is to pass oxygen (O_2) through a plasma produced by Dielectric Barrier Discharge (DBD). A planar surface DBD reactor was developed, comprising a dielectric barrier made of Bakelite with dimensions 190 x 140 x2 mm^3 (Fig.3). The electrodes are made of aluminum adhesive strip placed on the opposite sides of the plate. The high voltage electrode consists of 10 strips of dimensions 170 x 3 mm^2 while the ground electrode is an aluminum strip bonded to the other face of dimensions 170×120 mm^2.



(a) (b)

Figure 3. Bottom (a) and top (b) view of the flat ozone generator (all dimensions in mm)

2.3. Experimental procedure

Fresh foods bought at the local market were placed in both rooms and kept in storage for a period of 20 days. Photos were taken at regular intervals for visual analysis of food quality. In addition, mass weighing were taken to estimate food weight loss over time.

The weight loss was calculated using the following formula:

$$\Delta m = (m_i - m_f)/m_i \quad (1)$$

with

m_i : initial mass (1st Day)

m_f: final mass (20th Day)

The typical ozone concentrations typically used for the treatment in cold food storage rooms should be in the range 2-7 ppm (Ewel et al, 1938). Consequently, a time control system has been developed using Arduino card programming to control the On /Off time periods of the ozone generator to ensure a continuous ozone concentration ranging between 2 and 7 ppm.

To achieve these concentrations, preliminary tests were carried out to determine the optimal operation periods of the ozone generator. All the experiments were performed under stable conditions of temperature (15 ± 5 ° C) and humidity (50 ± 10%) inside the storage room

3.Results and discussions

The results of the preliminary experiments are plotted in (Figs.4 and 5), represent the evolution of the ozone concentration during the operation of the ozone generator (Period On) and the decline of the concentration during the shutdown (period Off) of the generator, respectively.

As shown in Figure 4, the time duration required to reach an ozone concentration of 7 ppm is 10 seconds. Moreover, the results presented in (Fig.5) show that the duration during which the concentration decreases from 7 to 2 ppm according to the humidity and the temperature conditions is 15 minutes.

Based on these results, the time control system of the ozone generator has been set to maintain an ozone concentration between 2 and 7 ppm, corresponding to an operating time of 10 seconds applied at shutdown intervals of 15 minutes.

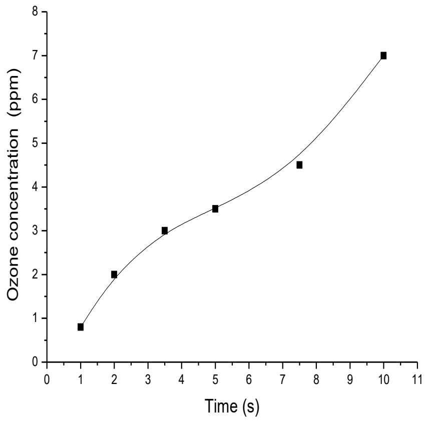


Figure 4. Evolution of the ozone concentration as a function of the operating time of the ozone generator

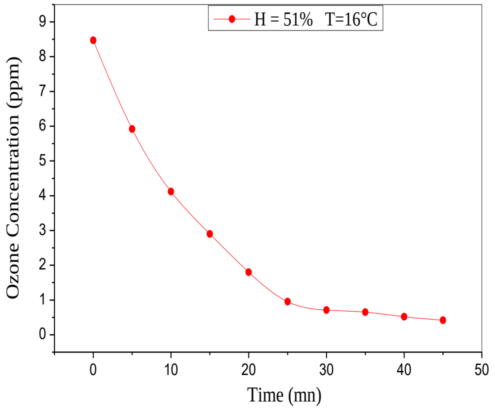


Figure 5. Decline of the ozone concentration as a function of the time during the shutdown of the ozone generator

Five food products were tested: tomato, cucumber, zucchini, apple and banana. (Fig. 6) shows photographs taken after 24 days of storage, in both treated and untreated enclosures.

These results clearly show that the visual aspect of the products stored in the ozone-treated room is much better. Indeed, the ozone is a powerful oxidizer that has been recommended by several researchers (Liew et al, 1994; Sarig et al , 1996) to reduce the decomposition of the product and prolong the storage period, eliminating bacteria and stopping their development. Ozone also reacts with ethylene, the gas responsible for the ripening of fruits and vegetables because it causes damage and increases decomposition (Skog, L. J & Chu, 2000 ; Suslow, 2004; Tayyari et al, 2017). In addition, it is mentioned in several studies (Smilanick et al, 2003; Tuffi et al , 2012; Montesano et al , 2004) that the exposure of fruits and vegetables to ozone can slow the sporulation of fungi harmful to citrus fruits, especially Geotrichum and Pennicilium.

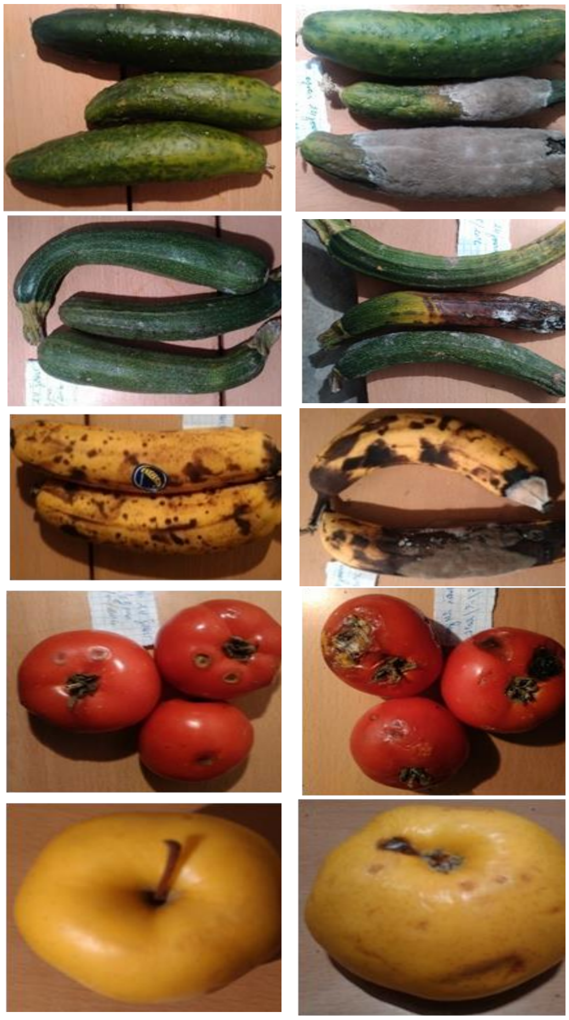


Figure 6. Comparison between the states of ozone-treated and untreated food products after 24 days

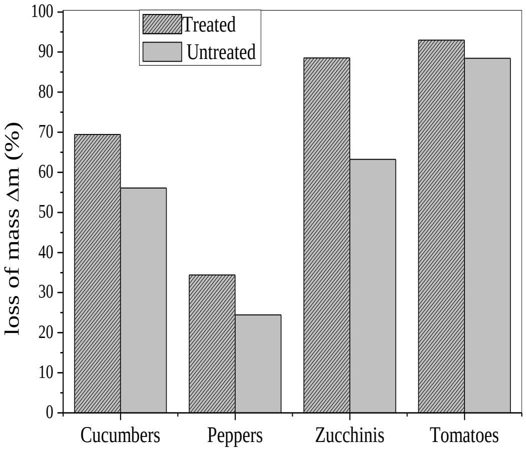


Figure 7. Mass loss of the food products after 24 days of storage

Moreover, the loss of mass after 24 days of storage has been analyzed; the obtained results are plotted in (Fig.7) which represents the difference between treated and untreated products in terms of mass loss. In addition to the longer food storage shelf life of the products, the loss of mass is much smaller for the products stored in the ozone-treated room, which thus represents a significant profit for the users.

Furthermore, the energy consumed by the ozone generator could be estimated by measuring the power of the ozone generator.

Lissajous figure plotted in (Fig.8) was used to analyze the consumed power. The energy consumed during one cycle of the discharge can be expressed as :

$$P = \frac{1}{nT}\int_0^{nT} v(t).i(t)dt \qquad (2)$$

Where T is the period of applied voltage, $i(t)$ is the current flowing through the discharge reactor and $v(t)$ is the applied voltage. Since the current is flowing through a measuring capacitor C, it can be expressed as:

$$i(t) = \frac{dq}{dt} = C\frac{dV_C}{dt} \qquad (3)$$

where V_C is the voltage across C and q is the transported charge in the ozone generator, then the energy consumed per one cycle can be calculated by the following equation:

$$W = \frac{1}{nT}\int_0^{nT} v(t).C.dV_C = \frac{1}{nT}\int_0^{nT} v(t).dq(t) \qquad (4)$$

Therefore, since the energy consumed during one cycle of the discharge is equal to the enveloped area of Lissajous (equation 4), the power P can be calculated by multiplying this area W by the frequency f

$$P = W.f \qquad (5)$$

According to equation (5), the power consumed deduced from the Lissajous figure plotted in (Fig. 8), is equal to 40 W, corresponding to 16 W/m^2.

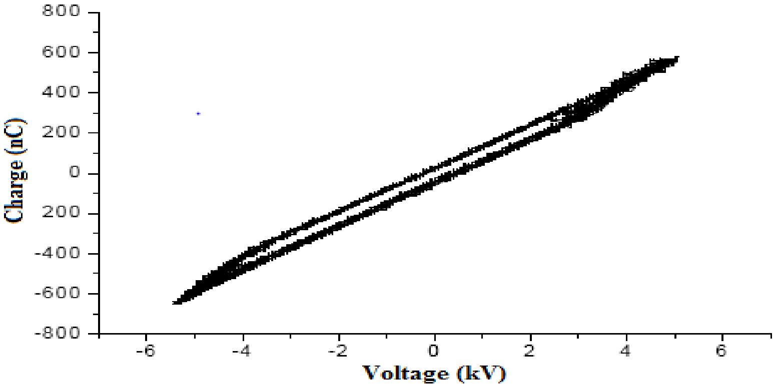


Figure 8 . Lissajou curve of the ozone generator

4. Conclusions

Although that several studies have been developed in ozone food conservation during recent years, we have noticed that there is a lack of studies on the use of this process in isolated sites not fed by conventional electric energy.

The results presented in this paper confirm the disinfection action of the ozone in food storage rooms by extending the shelf life of fruits and vegetables, by using a photovoltaic solar system that is the only solution in isolated sites.

The inverter developed using usual components such as transistor, Mosfet and a command by Arduino strongly reduces the cost of the installation.

Indeed, it has been proved through the experiments carried out, that an ozone production system supplied by a PV solar system for food storage offers a cost-effective and well-adapted solution for isolated sites.

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