Increasing the Efficiency of Ozonizing Devices in Agriculture

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Abstract. There is a sufficient degree of using ozone in agricultural production. First of all, it is used for equipment and poultry farms’ rooms disinfection, water sanitation for animals’ watering and for air and food treatment as well. There are some other known uses of ozone in agriculture. Needed amount of ozone can be generated with different electrical and physical methods. Ozon synthesis in the barrier discharge is the most common. There are given recommendations for ozone generators constructive settings in the researches. They are magnitude and frequency of the connection voltage; surface area and constructive features of the electrodes and a gap between them. Furthermore, they are composition and characteristics of the air for ozone synthesis, temperature and humidity level. A construction of ozone generator was developed and patented according to the results of the research. A scheme of a power source for ozone generator is given. It increases the efficiency of ozone production and decreases its cost.

1. Introduction

It is well known that ozone is one of the strongest and most effective, environmentally friendly oxidizer due to its chemical properties. It has the property of decomposing harmful and hard-to-remove substances. It does not require expensive raw materials. Therefore, it is widely used in agricultural production, for wastewater treatment, in medicine and hygiene, in environmental protection and industrial synthesis, for food disinfection, as well as in many other technologies. Ozone can be produced in various ways. First of all, by the use of ultraviolet light, electrolysis, and high-voltage discharge.

Further comprehensive research on ozone will help to expand the field of application. Let us consider the well-known scopes of application of ozone. First of all, in the field of agricultural production. Wheat grain is one of the most valuable crops [1]. The search for effective ways to reduce the toxicity of grain and grain mixtures is of scientific and practical interest. One of the most environmentally friendly methods of grain disinfection is ozonation. A positive effect of ozone on reducing the toxicity of wheat grains and grain mixtures was established as a result of research by these authors [1].

Interesting results were received on the decontamination of apples with ozone [2]. During the experiment, ozonated air was forced through a column of apples weighing 540 kg for a certain period of time. The incoming air passed through an ozone generator with low air speeds (0.022 m/s). The study reduced the number of bacteria on the surface of apples (colony forming unit, CFU). This indicates the effectiveness of ozone-air treatment [2].
Ozone-rich air is mostly used for water sterilization. The process comes down to aeration of water in special tanks to increase the content of dissolved oxygen in water [3]. Ozonated water is used not only for food purposes, but also for various technological processes. The ability of ozonated water to effectively disinfect pathogenic microflora of chicken meat was evaluated in this work [4]. The ozone generator used in the study has a production and solubility in water of about 523.67 mg/hour and 0.21 mg/l. Changes evaluated in this research include ozone effect times (40, 80, and 120 minutes) and replacement of ozonated water (twice, three times, and without replacement). Studies have shown good results for disinfect Escherichia coli and TBMA.

The half-life period is an important parameter of ozone for disinfection of various premises, including the creation of an ionic composition in agricultural premises and greenhouses. This parameter largely depends on the humidity and temperature of the air in the room [5, 6]. An approach to establishing the mechanism of air ion formation on the example of greenhouses has been studied and proposed [7]. It is established that the use of a small ultrasonic air ion generator helps to normalize the air ion composition of the air without the formation of harmful substances [6].

Ozone has unique biological properties for use in medicine in terms of therapy, sanitary treatment of premises, tools and equipment. In this case, it is recommended to use oxygen instead of air to produce ozone [8,9]. The air contains up to 78 % nitrogen, which is toxic for medical use. The generator with a double dielectric barrier discharge (DDBD) allows to obtain the optimal dose of ozone for use in the medical field. There is a space between two barriers that serve as a place for supplying pure oxygen and producing high-quality ozone in this reactor [9].

There is an increase in the demand for ozone in many areas. However, it is not enough due to the high costs of its production. The energy efficiency of modern ozonators is still low. Therefore, an urgent task is to increase the productivity and efficiency of ozonators.

Let us consider some types and characteristics of known ozonators [10-18]. Traditional tubular reactors and an amplitude-modulated current source were investigated in the study [10]. The ozone generator has the ability to adjust the ozone concentration simultaneously with a constant ozone output. It is established that the ozone generator has an almost constant ozone output 51.68 ± 2.97 g/kWh in the range of energy densities 50-350 kJ/m³. The maximum ozone output is 92 g/kWh.

Performance technology of dielectric barrier discharge plasma (DBDP) has been conducted in the survey of ozone generators [11]. The ozone was produced by DBDP reactor with voltage variation from 0.5 to 14 kV and a fixed air consumption of 10 L/min. A performance of 98 grams/hour with a power consumption of 126.5 watts was obtained depending on the shape of the DBDP reactor electrodes. Another form of electrode is able to produce 78 grams/hour. The power consumption of the reactor of this model is 64.8 watts. The maximum temperature inside the reactor reaches 49 ºС after 280 minutes of exploitation.

The overall dimensions of the reactor and the material properties affect the productivity of the ozonator [12]. Research results show that the dielectric constant is the main factor affecting the production of ozone, which growth decreases the breakdown voltage of the gap. It is shown that ceramic alumina has a better saturated concentration, which increased by 136%, in comparison to the empty layer.

Technologies where ozone is used were presented earlier (above). The range of applications of ozone can be expanded by creating new constructions of ozonators and reducing the cost of its production. The results of research of technical and energy characteristics of ozonators of different designs were presented in the works which are available to the authors [10-18].

Results on the energy consumption of an ozone generator with different constructions of electrodes for the dielectric barrier discharge of a plasma reactor are given in [14]. The reactors have a spiral-cylindrical shape. The power consumed by the reactor is 177.60 W and the concentration of ozone is more than 20 ppm at 10 turns of the spiral, the supply voltage up to 25 kV and the maximum frequency of 23 kHz.

The complex model of ozone generation combines physical processes in micro-discharges with the chemistry of ozone formation [15]. The authors assume a maximum efficiency of 33%, which
corresponds to 0.22 O$_3$ molecules per eV or 400 g of ozone per kWh. The highest ozone output is about 250 g/kWh in pulse ozonators.

2. Results and discussion

The energy rates and the productivity of the ozonator can be improved by the optimization of the constructive and electrical characteristics and circuit designs.

Some of these parameters have been determined from the literature. In particular, the relationship between the performance and frequency of the supply voltage for the ozonator is known.

For a given concentration, the ozone performance can be determined

$$Q = \sigma \cdot K$$  \hspace{1cm} (1)

where $\sigma$ - gas volume velocity, m$^3$/s

$K$ - ozone concentration in the air-ozone environment, g/m$^3$

The concentration of ozone can be determined under certain conditions:

$$K = K_s \left(1 - e^{-k_1 f} \right),$$  \hspace{1cm} (2)

where $K_s$ - the stationary concentration of ozone, g/m$^3$;

$k_1$ - the sum of the constants of the rates of formation and decomposition of ozone, divided by the unit of specific discharge power, m$^3$/W-s;

$P$ - active discharge power, W.

The discharge power depends on the gas pressure in the ozonator:

$$P = P_a \cdot (1 - k \cdot \rho_o),$$  \hspace{1cm} (3)

where $P_a$ - outdoor discharge power;

$\rho_o$ - the gas pressure in the ozone generator, kPa;

$k$ - coefficient for accounting for gas pressure, 1/kPa.

The power at atmospheric pressure of the gas in the ozonator is determined by a well-known expression:

$$P_a = 4 \cdot U_g \cdot f \cdot \left[(U_o - U_g) \cdot C_b - U_g \cdot C_\sigma\right],$$  \hspace{1cm} (4)

where $U_g$ - conditional burning voltage, V;

$f$ - frequency of the supply voltage, Hz;

$U_o$ - the operating voltage at the ozonator, V;

$C_b$ and $C_\sigma$ - the capacity of the dielectric barrier, and the capacity of the discharge gap, F.

The last expression showed that the power is proportional to the frequency and capacitances of the dielectric barrier and the discharge gap.

In turn, the size of the discharge gap depends on the supply voltage of the ozonator

$$\Delta_{gap}^{opt} = \frac{0.5 \cdot 10^{-3} \cdot U_o - 0.5}{16.5 \cdot (\rho_o + 100)}$$  \hspace{1cm} (5)

Formula for determining the frequency of the supply voltage for the ozonator at which the maximum concentration of ozone at the output of ozonating elements is reached:

$$f = \frac{4 \cdot U_g \cdot F \cdot \left[(U_o - U_g) \cdot C_b - U_g \cdot C_\sigma\right] \cdot (T_y^0 - T_a)}{R + \frac{1}{m \cdot C_p} \cdot (1 - k \cdot \rho_o)},$$  \hspace{1cm} (6)

where $F$ - area of the discharge zone of the ozonizing element, m$^2$;

$R$ - thermal resistance of heat transfer in ozonating elements, (K·m$^2$)/W

$m$ - specific consumption of the cooling environment per unit area of the electrodes, kg/m$^2$·s;
- specific Isobaric heat capacity of the cooling environment, \( J/(kg \cdot K) \);

- the maximum possible surface temperature of the dielectric barrier, at which the high reliability of the dielectric is still maintained, \( K \);

- temperature of the cooling environment at the inlet of the ozonizing elements, \( K \).

Ozonators have been developed and patented based on these findings [19]. The technical solution is to increase the productivity and reduce energy costs for ozone production. Figure 1 shows the ozone generator: top view and section by A-A; 2 - Functional diagram of an ozone production plant.

![Figure 1. Reactor with a double dielectric barrier discharge: a) - top view, b) - section by A-A.](image1)

![Figure 2. Functional diagram of an ozone production plant.](image2)

The device for producing ozone contains a reactor with a double dielectric barrier discharge 1 (Fig. 1). It is made in the form of consecutively connected flat windings 2 with a thickness of 0.01-1.0 mm, separated by dielectric plates 3 and a slot discharge gap 4.

Frequency Converter FC (Fig. 2) contains: two consecutively connected power transistors VT2 and VT3, a control unit CU with a master generator MO and a pulse generator PG, the adder NV, the step-up transformer TU1 with a primary L1 and secondary windings L2, voltage divider RP, variable capacity capacitor C3, logic elements D1 and D2, resistors R1 and R2, constant capacity capacitors C1 and C2, control transistor VT1.

In a conventional pulse converter, the current flowing through the power transistors is maximal by the time they are closed, the quasi-resonant mode (as in our case) differs in that by the time the power transistors are closed, their collector current is close to zero, which reduces losses. A reduction of the current at the time of closing provides the reactive elements of the device: the inductance of the windings L1 and L2 of the transformer TU1, the inductive and capacitive component of the flat windings 2 DDBD 1 and the variable capacitance of the capacitor C3. It differs from the resonant one
in that the conversion frequency is not determined by the resonant frequency of the collector load. This allows to adjust the output voltage by changing the conversion frequency and realize the stabilization of the output voltage and thus the performance of ozone.

The inductive component of the flat windings 2 and the variable capacitance of the capacitor C3 are consequently connected and at a certain frequency, a voltage resonance occurs. This leads to the fact that the voltage on the capacitance C3 and the inductance of the flat windings 2 exceeds the value removed from the winding L2 of the step-up transformer NU, which increases the performance of DDBD ozone 1 and the entire device as a whole.

When the power source "+", "-" is switched on, the control transistor VT1 of the master generator MO is closed, the generator frequency is maximum and is determined by the time constant of the circuit R1 and C1. Power transistors VT2 and VT3 switch with the same frequency, while the voltage on the secondary winding of the transformer increases and the ozone performance increases. At a certain voltage value, the signal from the divider increases to such a value that in the adder NV, the control transistor VT1 is limited by the feedback signal. The control transistor VT1 opens, there is a decrease in the pulse frequency of the master generator MO, which stabilizes the output voltage on the winding L2 of the transformer TU, and consequently, the performance of ozone.

A prototype ozone generator and control unit were developed and built based on the results of the study, (Fig. 3). The current frequency of the converter can be pre-set with the resistor from 15 to 25 kHz, and the output voltage from 9 to 15 kV.

The following devices were used to study the characteristics of the ozonator: at the inlet of the installation (Fig. 2) the voltage and current were measured with a voltmeter E515/2 (7.5-60 V) and an ammeter E514/5 (5-10 A). Power is obtained as the product of current and voltage.

The voltage at the discharge gap was measured with an electrostatic kilovoltmeter of type C196. The ranges of the readings: 7.5; 15 and 30 kV. It has a large input resistance (353 ± 2 % Mom).

The air supply was performed by a Quattro Elementi PACIFIC-50 compressor. The output capacity of the compressor is 155 l/min. The air speed was measured with a Testo 410-2 anemometer (measuring ranges from 0.4 m/s to 20 m/s). The device for measuring the concentration of ozone IKOZH-5K allows to measure the content of ozone in gas from 0.5 to 100 mg/l and in water from 0.5 to 10 mg/l.
3. Conclusions
It was established as a result of the test of the prototype:
1. The power consumption of the unit is 190-230 W.
2. The ozone productivity is 10.6-12.9 grams/hour.
3. These results conform to the world’s best ozone prototypes.

4. References
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