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Research and Development of System Elements of Automatic Control and Regulation of Ozone Concentration in Enclosed Space

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Abstract: A study is considered the mechanism of generation and decomposition of ozone in a gas phase, covering the main physical and chemical processes in the corona discharge. It is given the qualitative picture of ion distribution O^-, O_2^-, O_3^-, O_2^+ and electrons in corona-forming layer of a negative corona. On the basis of volt-ampere characteristics, there are made the calculated values of ion density of ozone and oxygen on border of a corona-forming layer. There was developed the ozonizer of high-frequency pulses of the type OVI-1, which is worked in the mode of the corona barrier discharge. It was developed the system of automatic control and regulation of ozone concentrations in the closed volume at high sensitivity and reliability of measurement results and it is reached by automation of measurement and data recording by the microprocessor and electronic system of regulation of ozonizer work.

Key words: Ozone, ozone generator, corona discharge, automatic control of ozone concentration, pulse ozonizer

INTRODUCTION

One of ways of increasing of efficiency of a number of technological processes in the food industry is use of ozone-air mixture. It is caused by participation of ozone in many biochemical processes which are a basis of a metabolism and energies in agricultural biological objects. The result of such use of ozone-air mixture are increase of productivity, decrease in energy intensity, decrease in bacteriological and viral oppression, increase of crop capacity, efficiency and safety of agricultural production. The problems of development of scientifically based technology of application electro-ozonization in agricultural production in connection with various areas of ozone use have the special relevance.

Development of highly effective ozone technologies and the ozone devices have a great importance and there is need research of theoretical provisions and the analysis of experimental data where the combination of them would allow to develop the scientifically based methodical mechanism of projecting of the given systems, taking into account requirements submitted by the food industry.

There was developed the ozonizer of high-frequency pulses of the type OVI-1 which works in the mode of the corona barrier discharge (Bakhtayev *et al*., 2010). As an electric barrier is served a glass with thickness in 1 mm and it is placed between corona and external electrodes of the ozonizing cell of ozonizer. For the corona barrier discharge of the ozonizing cell there is used high-voltage pulses with length of order about 75 mks and with the repetition frequency up to 4 kHz. There is developed the System of Automatic Control (SAC) of concentration of ozone in the working room. It is provided the technical specification on the Block of Automatic Control of Frequency (BACF) of ozonizer. There was made an algorithm and the program of controlling of MC (Micro-Controller) for the main operating mode of BACF. The electric circuit of internal connections of BACF. On basis of the obtained data there was developed the technological scheme of ozonization for disinfection and sanitation of atmospheric air in the work areas.

MATERIALS AND METHODS

The main ionization processes in the corona discharge are proceeded in the area of the high field intensity (in a corona-forming layer) which is lain near with electrode face with a small radius of curvature (a wire, corona point, etc.). At some voltage between electrodes, there are started to arise the separate electronic avalanches or groups of avalanches. With voltage rise and achievement of initial intensity of a corona field (E_0) these avalanches are created an appearance of sufficient number of the free electrons which are given beginning for formation of new avalanches. Discharge current

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sharply increases; the mode of the independent discharge is set up. For calculation of parameters of the separate avalanches and also for identification of criterion of independence of the discharge there are usually used α and γ ionizing coefficients of Townsend.

For formation of ozone the optimum conditions are created in the negative corona, processing in atmospheric air, oxygen and their mixtures with other gases. Thus, electrons have high energy in ionization area whereas gas molecules in external area of a corona are in a condition of thermal energy. Due to the spatiotemporal discreteness of the electronic avalanches in a corona cover, the mechanism of formation of ozone in a negative corona can be divided into three stages conditionally.

Beginning, development and the finishing of an electronic avalanche in the field of a corona-forming layer ($\sim 0.3\sqrt{r_0}, c_M$) time of existence of an avalanche 50-100 ns. In this stage there are processed: beginning, multiplication and partially, disappearance of electrons, dissociation, ionization and molecular excitation of oxygen.

Processes of electron attachment and beginning of oxygen negative ions, reactions of atoms and the molecular excitation of oxygen with other molecules, ozone formation and its relaxation in the main state. Processes are made in a corona-forming layer, the second stage time is ~5-10 mks.

"Spreading" of ozone neutral molecules in surrounding space due to diffusion or departure because of gas purging; finishing of slow reactions; "resolution" of oxygen negative ions and ozone in external area of the discharge. The stage time is ~1-10 ms.

Formation of oxygen negative ions and ozone in the corona-forming layer is processed effectively because of positive affinity with electrons O (1.46 eV) and O_2 (0.44 eV) and it more belongs to O $_3$(2.1 eV). In connection with charge carriers in external area of the discharge are negative ions of oxygen and ozone, so there is constantly processed the charge exchange of these ions:

$$O + O_2^- \rightarrow O_2 + O^-, \quad 3.5\times10^{-10} \tag{1}$$

$$O^- + O_3 \rightarrow O_3^- + O, \quad 5\times10^{-10} \tag{2}$$

$$O_2^- + O_3 \rightarrow O_3^- + O_2, \quad 3.3\times10^{-10} \tag{3}$$

Where the constants of reaction rates K were taken from researches of researchers (Smirnov, 1974; Lecuiller and Goldman, 1998). Unit of measurements K for reactions of the second order is cm^3/molecules and for the third cm^6/molecules in second. Constants are given for temperature by 300 K.

As, it was determined (Bakhtayev *et al*., 1991) at measurement of total mobility of negative ions of value (2.61-5.94), it is surpassed much more of tabular data (2.24-3.2) and it is possible to explain with a considerable share of presence of electrons in external area of a negative corona. Also, it was noted that maximum of coefficient of attachment in atmospheric air lies in the field of energy of an electron about 0.4 eV and therefore, the part of negative ions is formed out of a corona-forming layer of the discharge. It is also necessary to assume that concentration O_3^- in a discharge gap must be prevailed over concentration of neutral molecules of ozone (Gernak *et al*., 1979). It should be noted in this regard that electrons having big energy at a wire surface at approaching to border of a corona-forming layer considerably lose it because of weakening of electric field. If on border of a corona-forming layer (41 V/cm. mm of mercury) the electron has energy more 3 eV but with removal from a corona-forming layer, i.e., in external area, its energy will become to order about 0.5÷1 eV.

Other defining factor for the corona discharge is value of coefficient of attachment of electrons to molecules and atoms of gas which fills a discharge gap. It was noted that values of coefficient of attachment of electrons in air and in pure oxygen are significantly differ from each other and depend on the extent of energy of electrons (Masuda, 1986). Thus maximum of coefficient of attachment for oxygen is lain in the area of energy of an electron 2.2 eV and for air <0.4 eV and for oxygen its value above on the order than for air. It means that electron trapping of molecules and atoms of oxygen is happened intensively in a corona-forming layer whereas in atmospheric air processes of attachment of electrons are considerably removed in external area of a corona.

The ratio of density of an electronic component of current of a corona j on distance r to initial j_0 on border of a zone of ionization r_i is determined for cylindrical system of electrodes by the following expression (Mack-Danielle, 1967):

$$\frac{j}{j_0} = \exp\left[-nQ\frac{2\varepsilon}{m_e}\times\frac{r}{V_e}\right] \tag{4}$$

Where:

- n = Concentration of neutral molecules of oxygen
- Q = Total interaction cross-section of electrons
- ε = Energy of electrons
- m_e = The mass of electrons
- V_e = The speed of the electrons, leaving a zone of ionization of the corona discharge

Calculations are given the following results: for oxygen at distance r = 0.3 mm this ratio was made j/j_0 = e-30 while for air at distance r = 0.65 mm it was equal j/j_0 = 0.5. It is really possible to note that electronic component of total current of a corona is negligibly small in oxygen and it is large in air. An essential contribution of electrons to the general current of a corona in atmospheric air are also noted by other researchers (Mnatsakyan *et al.*, 1968).

At determination of mobility of negative ions in a unipolar corona there was considered presence of a number of stable ions of oxygen at atmospheric air (O^-, O_2^-, O_3^-). Now, to this row, it is necessary to add low-energy electrons in external area of a corona which are presented and are originated at various chemical reactions in the discharge and further are participated only in attachment processes. Besides, these ions in a discharge gap are reacted with molecules and atoms of gas, forming other kinds of atoms and molecules (O, O_3).

Detailed discussion of physical and chemical processes in a corona cover and the description of the electrochemical reactionsa involved directly or indirectly to electrosynthesis of ozone are not decide the issues of density distributions of ozone in a discharge gap. In this regard, it should be noted that the calculated data, obtained in research (Bakhtayev *et al.*, 2007b) will be able to afford to construct a qualitative picture of density distribution of ozone and other charge carriers in a corona-forming layer. Thus, there is used the simplified scheme of a discharge gap, when processes of forming and disappearance of ozone and other charged particles are processed only in a corona cover and out of border of a cover to an external electrode there is proceeded the unipolar ion flows. It is natural to assume that density of ions of ozone and other charge carriers on border of a corona cover will be maximum and then at the movement to an external electrode their density will be decreased and it is connected with geometry of a discharge gap (for example, cylindrical system of electrodes) (Fig. 1).

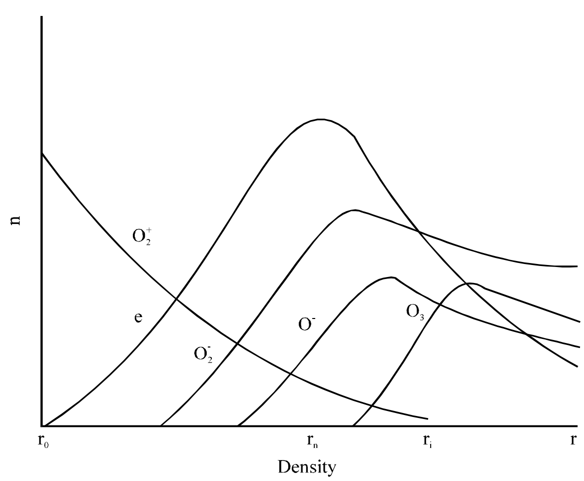

Fig. 1: Density distribution of ozone ions (n) in a corona cover

As the basis for creation of dependences of density distribution of ozone ions and other charged particles from distance to a corona wire there were served the following circumstances:

- The data of high-quality interpretation at consideration of structure of a corona cover
- Calculated data of the kinetic equations describing elementary processes in a corona cover
- Diagrams of electrochemical reactions in a corona cover, involved in ozone synthesis

These circumstances are significantly supplemented in the spatiotemporal plan with consideration of a single electronic avalanche, characteristic for a negative corona on MP. The ionization process, begun with one or several electrons on a wire surface, is roughly developed further, extending to border of the corona-forming layer which is at distance $0.3\sqrt{r_0}$. According to modern data, the electronic avalanche represents almost symmetric and spherical dilating cloud where for it there are pulled the trace of the ionized and excited atoms and molecules and it is symmetric concerning the direction of external electric field (Lozansky and Firsov, 1975).

For determination of parameters of electronic avalanches there is usually used an electric method, measuring characteristics of current pulses on discharge electrodes (Trichel pulses) that allows to divide electronic (the pulse front) and ionic (pulse duration) components of electronic avalanches. It is too difficult to judge about volume of contribution of ozone ions to total discharge current and to define quantity of the made ozone in the discharge (Bakhtayev *et al.*, 1992).

At that moment, the solution of this task by means of system of continuity equations for charged particles is impossible as there are no initial conditions for ions and it is also presented the densities of neutral atoms and molecules of oxygen and ozone at the equations. Besides, drawing up of balances of ions on electrochemical reactions is led to even more lengthy material and finally, to uncertainty of the solution of a task.

Thus, there is almost only one way for determination of quantity of ozone and it is an experimental measurement of concentration of ozone in air or in gas, blown through a discharge gap.

Therefore, it is more acceptable the way of determination of ion density in a discharge gap including ozone ions, through the discharge current magnitude which can be measured and determined by volt-ampere characteristics of the discharge. For cylindrical system of electrodes the current magnitude of a unipolar corona is determined by known formula (Kaptsov, 1947):

$$I = 2\pi rnekE \tag{5}$$

Where:

- r = Distance from an axis of cylindrical system of electrodes (cm)
- n = Ion density (cm^{-3})
- k = Ion mobility (cm^2/Vs)
- E = Field intensity in corona external area (V/cm)
- e = Electron charge, 1.6×10^{-19} (As)

For a correctness of the solution of the task, there will be made a number of assumptions: in the corona external zone there are no processes and reactions which would change a rating or ion density and on the radius of the cylinder there is observed ratio $n_1r_1 = n_2r_2$.

In the corona external zone of the ion mobility, O^-, O_2^-, O_3^- are accepted constant and equal according to $k_1 = 3.2$, $k_2 = 2.24$ и$k_3 = 2.54$ cm^2/Vs.

Intensity of electric field in an external zone of the unipolar corona at an assumption of constancy of the ion mobility there is approximately described by the equation (Bakhtayev, 1984):

$$E = \sqrt{I/2\pi\varepsilon_0 k + E_0^2 r_0^2/r^2} \quad (6)$$

Where:

- E_0 = Initial intensity of the corona field which is determined by a Pick (1934) formula (V/cm)
- r_0 = Radius corona MP(cm)
- $_0$ = Dielectric constant (F/cm)

Because the second member under a root $E_0^2\, r_0^2/r$ is small magnitude in comparison with the first member, E in external area has constant value and depends only on I.

Now, having entered for convenience of designations of ion density O^-, O_2^- and O_3^- in the form n_1, n_2 and n_3, respectively, there will be written down the Eq. 6 as follows:

$$I = 2\pi reE\,(k_1n_1 + k_2n_2 + k_3n_3) \quad (7)$$

And, if to use ratios for calculations, there will be received $n_1 = n_3/1.28$ and $n_2 = 1.32n_3$. After their substitution in the Eq. 7 and some operations, there will be determined the expression for density of ozone ions:

$$n_3 = \frac{I}{2\pi r_i eE\left(\frac{k_1}{1.28} + 1.32k_2 + k_3\right)} \quad (8)$$

where, r_i the radius of border of a corona-forming layer, equal $0.3\sqrt{r_0}$ cm. Calculations for this formula for the ozonizing cell with the following parameters $r_0 = 5\times10^{-3}$cm, $r_i = 0.3$ cm, $I = 0.166\times10^{-3}$A cm^{-1}, E = 12 kV/cm give $n_3 = 8.19\times10^{10}cm^3$, $n_2 = 10.8\times10^{10}cm^3$, $n_1 = 6.4\times10^{10}cm^3$.

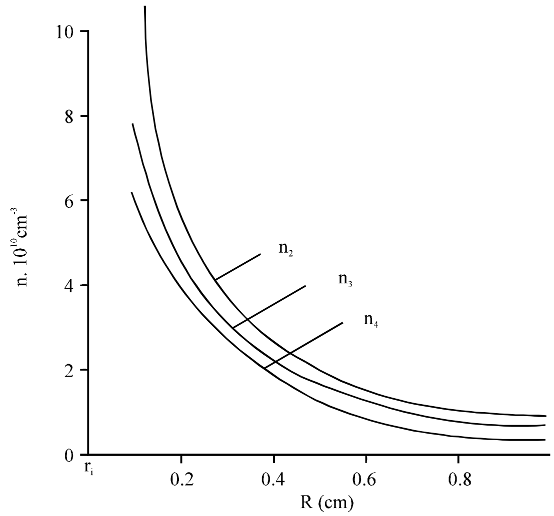

Fig. 2: Density distribution of ions about O^- O_2^- and O_3^-

In view of the fact that these values are corresponded to ion density O^-, O_2^- and O_3^- on the border of a corona-forming layer, for clarity there are constructed the curves of density distributions of ions n_1, n_2 and n_3 in an external zone of the discharge (Fig. 2).

There wasn't taken into account in calculations the electronic component of discharge current, though it is perceptible near of corona cover. As air is the electronegative gas, consisting of atoms and molecules of oxygen and ozone having high electron affinity (O 1.46, O_2^- 1.8, O_3 1.96 eV) in external area of the discharge there is no electron flow, as such, though it constantly participates in processes of "attachment" and "detachment" up to an external electrode (Dzhuvarly *et al*., 1988).

Estimated calculations and data of some researchers (Gernak *et al*., 1979) showed that ozone because of the high electronic affinity in the discharge is existed generally in the form of negative ions, which having reached an external electrode were become neutral and leave a discharge zones. In this case for increase of productivity and work efficiency of the ozonizing cell it is necessary the air blowing of the discharge gap (Bakhtayev *et al*., 1994; Bakhtayev and Bokova, 1996).

Results of theoretical and experimental works of the last years were shown that the negative corona discharge from microelectrodes, (a micro-wire, a needle (corona point), sharp edges and a thin spiral with radiuses of curvature no more than 25-50 microns) in comparison with other types of the corona discharge, provides a higher specific current of the discharge and big density of current on the corona electrode (Bakhtayev *et al*., 1998; Abishev *et al*., 2001).

Productivity on ozone of any ozonizing element, first of all, depends on the discharge current magnitude and therefore, for decrease in specific energy consumption there is arisen a necessity of reduction of values of the supply voltage at the same currents of the discharge. There are some ways for current amplification of the corona discharge, conducting to increase of productivity of the ozonizing element. There can be considered their opportunities, merits and demerits at their usage in the ozonizing elements.

One of ways of current amplification of the corona discharge and it is equivalent to increase of productivity of the ozonizing element is reduction of interelectrode spacing of the discharge gap. In this case, at the same supply voltages it is possible to receive higher values of discharge current, if thus there is no breakdown between electrodes.

The next way of discharge current amplification can be served heating of the corona electrode or heating of the air, surrounding a discharge gap. In this case, with rise of air temperature there is risen an intensity of ionization in a corona-forming layer because of increase in free path of electrons and current density considerably increases in external area of a corona. It is determined that at heating air to 140°C and at the same values of supply voltage, discharge current is increased in the five fold but usage of this way for discharge current amplification is connected with a some difficulties of technical character, necessity in additional devices for air heating and then, its purges through the ozonizing element and also there is arisen necessity of thermal insulation of the ozonizing element from environment. Besides, at such air temperature (140°C) the most probable is ozone decomposition, received in the ozonizing element.

Results of research were shown that in all temperature ranges and air pressures, the characteristic of the corona discharge are functions only air density. Influence of air temperature on the corona discharge is described by the same regularity as dependence of air density on its temperature. Pressure of air or its density on the magnitude of the current discharge is influenced through initial intensity of a field of the corona discharge, which by turn, is determined the firing voltage in this gap (Bakhtayev and Grinman, 1975).

It is determined (Bakhtayev and Grinman, 1975) that reduction of air density, first of all, conducts to decrease in value of initial voltage of the corona discharge and the transconductance of volt-ampere characteristics, thus is considerably increased.

Now, we will consider output parameters of the ozonizing element with the lowered air pressures which are productivity on ozone (g h^{-1}) and specific energy consumptions (g kWh^{-1}). For this purpose, there will be used the characteristic of the ozonizing element received in research (Bakhtayev *et al*., 2007a) and approximating it, there can be found a formula for dependence of ozone output from current of the corona discharge:

$$P_{\Pi} = KI \quad (9)$$

Where:
P_p = Productivity on ozone (g h^{-1})
K = Proportionality coefficient (g h^{-1}×mA)
I = Current of the discharge (mA)

In magnitude of a tilt angle of the characteristic, it is possible to find the value of proportionality coefficient K = 0.2 g h^{-1}×mA.

Specific energy consumptions (P_s) are determined by ratio of productivity on ozone (P_p) to the energy consumption W = U×I kV an hour that is:

$$P_s = \frac{P_p}{W} = \frac{KI}{UI} = \frac{K}{U}\frac{g}{kV} \times h \quad (10)$$

Where:
U = Voltage between the electrodes (kV)
I = Discharge current (A)

As a matter of fact, P_s is depended on value U at a certain current, the less its value the P_s is above. A certain interest represents comparison of experimental values P_{PE} (P experimental productivity) with calculated P_{PCV} (P calculated value of productivity) on Eq. 9.

There are given in Fig. 3, the dependences of voltages (U) from air pressure (p) for various constant values of discharge current (I), measured at pressures, beginning from 100 mm of mercury up to pressure 680 mm of mercury, considering the air temperature is normal 20°C. Follows from these data that at constancy of values I and in case of decrease p, there is turned out that how much magnitude U is decreased, so many P_s is raised.

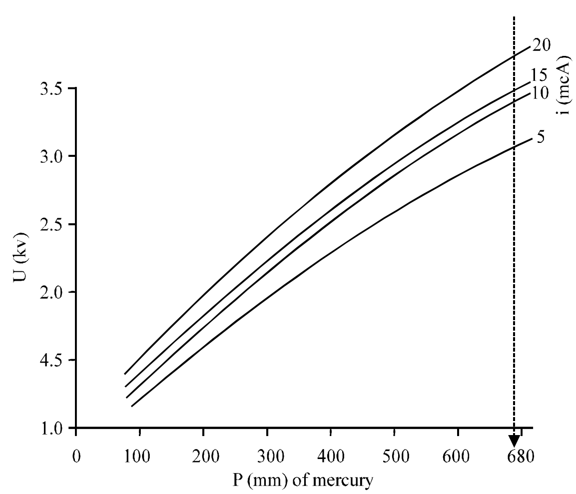

Fig. 3: Dependence of voltages from air pressure

Table 1: Output parameters of the ozonizing element at lowered air pressure

	I (mcA) 100				I (mcA) 400				I (mcA) 680			
P mercury (mm)	5	10	15	20	5	10	15	20	5	10	15	20
U (kV)	1.2	1.3	1.4	1.5	2.3	2.5	2.6	2.8	3.1	3.4	3.5	3.8
P_{pCV} (gh^{-1})	10^{-3}	2×10^{-3}	3×10^{-3}	4×10^{-3}	10^{-3}	2×10^{-3}	3×10^{-3}	4×10^{-3}	10^{-3}	2×10^{-3}	3×10^{-3}	4×10^{-3}
P_s (g kv$\times h^{-1}$)	166	153	142	133	87	80	77	71	64	58	57	52

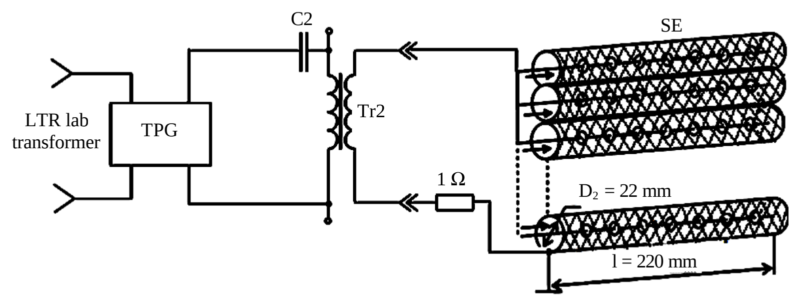

Fig. 4: Functional diagram of experimental installation: TPG = The thyristor pulse generator; C2 = The energy storage capacitor; Tr2 = The transformer; SE = Electrode system; D_2 = Diameter of tubes; l = Length of tubes

According to perfect gas laws, an air pressure decrease reduces a concentration of molecules of oxygen in air as well that can be lead to decrease in formation of ozone in a discharge gap. Meanwhile, decrease p leads to converse effect: to amplification of ionization processes because of lengthening of free path of electrons and therefore to increase of their energy. Thus, decrease p can not significantly have impact on degree of output ozone as at decrease p constancy of values of discharge current is provided with the necessary density of a charge flows, consisting generally from ions of oxygen and ozone.

There are specified, in Table 1, the productivities on ozone (P_{PE}) and specific energy consumptions (P_s) and also the corresponding values of U and I for three air pressures.

The main discharge processes at corona needle and at corona wire essentially don't differentiate and they are differed on a configuration of electric field and on discharge power. In this regard for research of influence of air pressure on characteristics of the corona discharge there was used the coaxial electrode system which possesses experimental simplicity and convenience and also it is the ozonizing element for receiving ozone in the corona discharge.

As, it follows from data of Table 1 at lowered air pressures, it is possible to receive quite high values of specific energy consumptions (166 g kWh^{-1}) which are the main advantage of this way of receiving ozone.

There was developed the ozonizer of high-frequency pulses of the type OVI-1 which works in the mode of the corona barrier discharge (Bakhtayev *et al*., 2010). As, an electric barrier is served a glass with thickness in 1 mm and it is placed between corona and external electrodes of the ozonizing cell of ozonizer. For the corona barrier discharge of the ozonizing cell there is used high-voltage pulses with length of order about 75 mks and with the repetition frequency up to 4 kHz.

Specific energy consumptions in the Pulsed Corona Discharge (PCD) dont exceed as such in the barrier discharge. Installation, on which there were conducted the experimental researches on ozone production in PCD with wide area ionization, is consisted of the high-current thyristor generator, the raising pulsing transformer with output voltage up to 3 kV. The installation scheme is given in Fig. 4.

Atmospheric air is moved in electrode system by means of the compressor. For measurement of ozone concentration there was used ozonometer which was fixed at the exit of the ozonizing cell. It was developed the installation for generating high-voltage pulses which were given on ozonizing cells of the corona barrier discharge (Bakhtayev *et al*., 2010).

At usage of ozone in the food industry the great attention must be paid to concentration of the emitted ozone for product processing. It is necessary to consider features of technological process, species composition of microflora, temperature, humidity and other parameters as well which can have impact on effect of ozone. In this regard, it was developed the device for ozonization with control automation and regulation of ozone concentration in premises of agro-industrial complex that it is actual.

For optimum selection and regulation of ozone concentration for various food stuffs, there was developed the generator for generating high-voltage pulses, given on ozonizing cells of the barrier discharge and the scheme of automatic control of ozone concentration in the enclosed space.

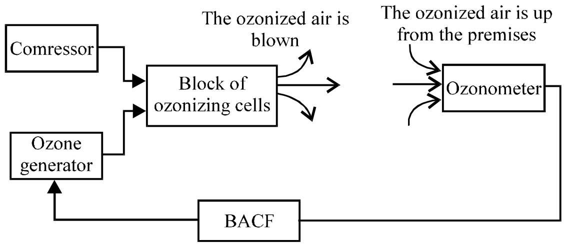

Fig. 5: The general block technological diagram of air ozonization in production

On the block technological diagram (Fig. 5) there is shown the block diagram of the experimental device for ozonization of production areas which is consisted of a source of high-voltage pulses: ozone generator; corona discharge cell, developing ozone; the compressor for ozone blowing from the ozonizing cells, an ozonometer; the block of automatic control of ozone concentration and differently the Block of Automatic Control of Frequency (BACF) of generator.

The experimental stand was developed for carrying out of preliminary researches. On the basis of the received results of preliminary experiments there were determined the following basic technical parameters of the prototype of an ozonizer of OVI-1: Voltage power 220 V, 50 Hz; power consumption 0.15 k W; the processed cubage 50 cbm; time of single action 10 min; gross geometries 240×210×110 mm; mass 4.5 kg.

Research of the prototype O VI-1 was conducted *in vitro* in the Kazakh Republican Sanitary and Epidemiologic Stations (KRSES) for the purpose of determination of productivity and ozone specific energy efficiency on the iodometric method.

RESULTS AND DISCUSSION

It is developed the device, joining an ozonometer and system of automatic control and regulation which is contained Ozonometer (OM) which quantity is defined by practical consideration according to the volume of the enclosed space, the Microprocessor (MP), intended for work on the given program at the mode choice for concentration of ozone and on time of ozonization of the enclosed space and a pulse Ozonizer (OZ) providing electronic regulation of ozone output on the frequency of high-voltage pulses (Bakhtayev *et al*., 2015).

The Microprocessor (MP) has a multipoint input for ozonometers and one output for the Block of Automatic Control of Frequency of high-voltage pulses (BACF). MP works according to the given program, it can make spot control of ozone concentration, summarize and average incoming data from ozonometer, generate the signals for regulation of ozone output from ozonizer.

Ozonizer productivity on ozone is determined by pulse frequency of ignition of a thyristor key therefore instead of the control mode of regulation of the high voltage there is used the Block of Automatic Control of Frequency of high voltages (BACF). At the mode of support of constancy of ozone concentration in volume, there is determined a defined frequency of the controlled generator of pulses of tiristor ignition which is corresponded to the given value of ozone contents. Any data deviation, total or average values, coming to input of BACF is compensated by change of off-duty factor of high-voltage pulses

Figure 6 is presented the function diagram of the device, partially located in the Closed Volume (CV). Ozonometers (OM) are placed in the Enclosed Space (ES) where there is measured the ozone concentration. The quantity of ozonometers and their location is defined by practical consideration. The Ozonizer (OZ) is partially placed at a zone of the closed volume and replenishment by fresh air is made outside of CV. The MP and BACF are placed out of zone of the Closed Volume (CV). In view of the fact that ozone-air mixture is pressurized in CV through the ozonizer by means of the compressor, so there can be formed a pressure air excess in CV. For stabilization of the working position there are used windows with Ozone Absorbers (OA) from porous silica gel.

Ozonometers are had the preliminary testing before installation at the workplace, there are found sensitivity and accuracy of measurement of ozone concentration, it is carried out graduation of ozone metric characteristics of ozone and also there is determined identity of their characteristics within an admissible error of measurement.

Then, it is come to the input of MP in the signal-voltage form from each ozonometer separately, where according to the given program the signals will be able to transform to the convenient form; where it is necessary for control of the BACF block. The BACF block is included an Ozonizer (OZ) which will be worked till the condition of the fixed ozone concentration in the Closed Volume (CV), thus and at the same moment, there is started to work the timer in MP. In view of the fact that ozone will be interacted with the product without fail which is in CV, its concentration will be constantly decreased and therefore, the ozonizer must be worked continuously, even if it will be in the mode with a small ozone output and it is need for ozone compensation.

There is offered to take the pulse ozonizer, developed by the researchers as an ozonizer (Bakhtayev *et al*., 2015).

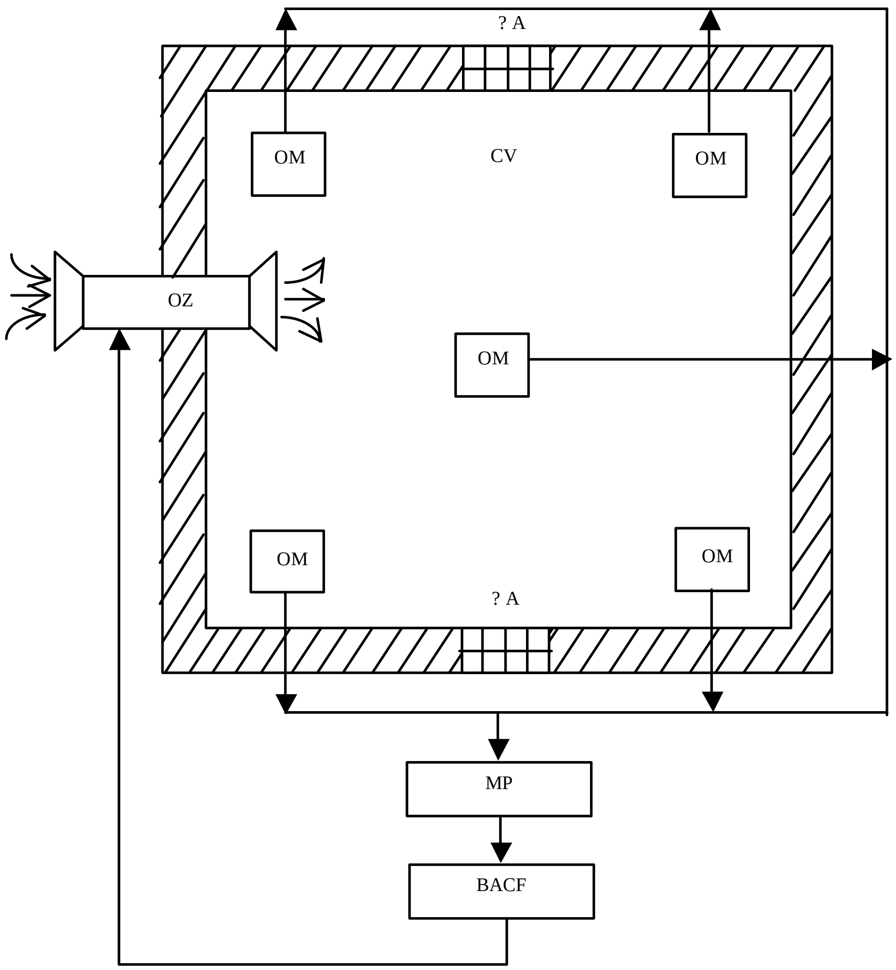

Fig. 6: A function diagram of the device for automatic control and regulation of ozone concentration

As it was told above, this ozonizer is easily controlled by BACF block and it has rather wide range of the output characteristics on ozone. For example, ozone productivity can be changed from 0.176-0.453 g h^{-1} and ozone energy efficiency from 13.87-55.5 g/kW/h, as an ozonometer, there was used the above described device which has the range of measurement of ozone concentration in air from 2-10 mgm^{-3} at ozonometer sensitivity to ozone about 0.2 mg/mcA.

Tests of the developed device were shown a correctness of the chosen principle of operation of the device and its working capacity in real conditions at multipoint measurement of ozone concentration with use of the microprocessor. The device provides automatic control and regulation of ozone concentration in the closed volume at high sensitivity and reliability of results of measurements where it is reached by automation of measurement and data recording by the microprocessor and electronic system of regulation by work of an ozonizer.

CONCLUSION

The received research results of the mechanism and kinetics of ozone electrosynthesis in a negative corona by the microwire are allowed to create prerequisites for development of the new principles of the ozonizers on the corona discharge with high energy yields of ozone and productivity. The developed ozonizer of high-frequency pulses, working in the mode of the corona barrier discharge, is easily controlled by changing of the pulse frequency.

In view of the fact that an ultimate goal of work is creation of system of automatic control and regulation of ozone concentrations in enclosed space, ozonometers on the corona discharge are used as sensors for control and measurement of ozone concentration as well and they are had power supply from one source with an ozonizer.

An actuality of the given work is followed from necessity of ozone output in useful capacity at processing for safety agricultural and foodstuff.

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