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Study on the Main Characteristics of Ionizers for Fruit Storage

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Abstract. This paper highlights the technological features of long-term storage of fruit products, the processes that take place during storage of fruit products, sources of waste, the effect of air ions on fruit and optimal air ionization regimes, the main parameters of the electric corona discharge ionizer. Experimental and theoretical research obtained under direct production conditions was also studied.

INTRODUCTION

Electric ionizers have a high efficiency and are used in various technological processes. Corona discharge air ionization devices have a simple design and are characterized by low power consumption. They can supply the room with high concentrations of unipolar light ions, the ions being driven by the electric forces of the discharge field [1-10]. The control of such devices is easy and the process can be fully automated. Ionization of air in fruit storage warehouses using electric ionizers improves working conditions and sanitary-hygienic condition of production rooms [11, 12]. In this case, it will be possible to sanitize indoor appliances and inventory, as well as products stored at no additional cost.

Corona discharge electric ionizers operate on the basis of excitation and ionization of gases in the air in an uneven electric field [13] with sufficient electric field strength on the surface of the electrodes of neutral molecules and atoms. Extreme unevenness of the electric field is achieved by using two electrodes with different surface curvatures. The first electrode has a sharp edge, the radius of curvature of the surface is very small and is called the corona discharge electrode, and the second electrode is almost flat or the radius of curvature of the surface is very large and is connected there. In some cases, there may not be a second electrode, and the product or building walls to be processed will remain grounded electrodes. The corona discharge electrodes can ionize the air if they have sufficient potential [14].

Muzafarov was engaged in determining the design parameters and placement of needle corona discharge electrodes, he used ionization devices in air purification filters and ozonators [1, 8, 9]. It has been shown that the electric field of the corona discharge is effective in the separation of air pollutants, especially microparticles of very small size. Different sources of current were used in the study: positive, negative, industrial frequency, and increased frequency current, taking the corona discharge and determining the optimal parameters for each case. The considered ionizers do not have a suitable design and technological requirements for fruit storage. They will require additional means to ionize large volumes evenly and sufficiently, as well as to maintain optimal regimes in the environment due to the characteristics of the storage chambers.

RESEARCH METHODOLOGY

To study the basic performance of an air electric ionization device, we consider their volt-ampere and volt-ion characteristics. To study the volt-ampere and volt-ion characteristics, indicators of the optimal operating modes of the device are obtained [2]. In our research, needle corona discharge electrodes were used because they have high

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mechanical strength compared to wire electrodes, intensive discharge at low voltages, and do not block the corridors of the storage warehouse [3].

To study the volt-ampere and volt-ion characteristics of an air electrification device, we use a corona discharge device equipped with a laboratory autotransformer with a voltage adjustable from 5 to 20 kV (Figure 1).

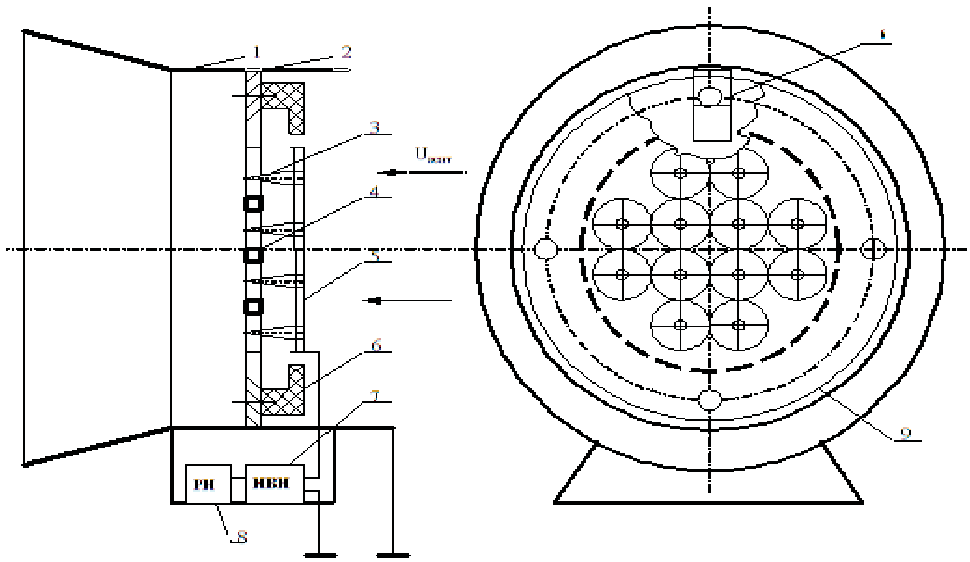

FIGURE 1. Corona discharge device for studying the volt-ampere and volt-ion characteristics of the air electrification device

The air was ionized by means of a needle discharge electrode with a needle electrode. The air ion generator consists of a corona discharge electrode, an earth-connected electrode, an insulator that separates them, a high-voltage current source, a housing, and fasteners. The discharge electrodes are supplied from a current source consisting of a small-sized transformer and a voltage-amplification circuit [4]. Electronizers can be located in one place or distributed throughout the room in accordance with the storage technology cooling and ventilation system [5].

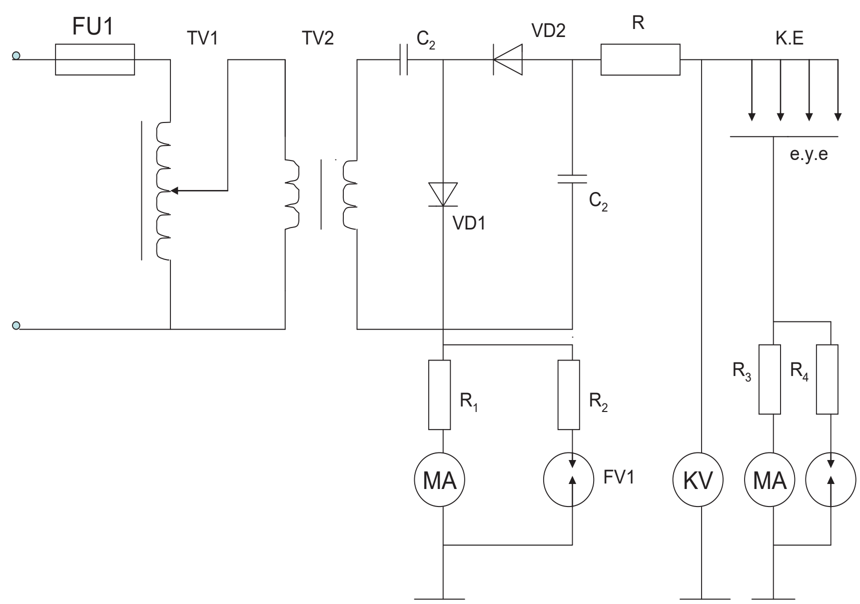

FIGURE 2. Wiring diagram of an electric corona ionizer. K.E-discharge electrode e.y.e- grounded electrode. R_8-high voltage divider, TV2- transformer. TV1-voltage regulator, FU_1, FU_2-dischargers. mA_1, mA_2-microammeters. kV-kilovoltmeter.

In the development of the electrolyzer, based on the technological requirements, its design, including the dimensions of the discharge system, is developed, and then the parameters are optimized. The optimization parameter is the concentration of ions in the air. The stand for the study of the electrolyzer consists of a current source, a voltage regulator, control and measuring instruments. To fasten the discharge electrodes, an aluminum frame in the form of a square was prepared and mesh at a distance equal to the distance between the electrodes. Corona discharge electrodes are of different sizes and are attached to the carcass at different distances. The electrodes are easily mounted and removed on the carcass, and various options are created in the studies [6, 7]. The amount of voltage at the electrodes is adjusted by the primary winding by means of an autotransformer. The voltage in the amplifier transformer is increased from 220 V to 6000 V and then in the voltage multiplier is increased to 20,000 V (Figure 2).

A microammeter type M-95 and a milliampervoltmeter Ts-4311 are used to measure the ionizer current on the grounded electrode side. The voltage at the electrodes is in the range of 0-7.5 volts. It was measured with an S-96 type static kilovoltmeter with 0-15 and 0-30 kV settings. An oscilloscope was used to record the commencement of the ionization process in the air during the corona discharge.

An extensive discharge process was observed in the ionizer when a voltage of 2.5-10 kV was applied to the discharge electrodes and the discharge distance was 10-50 mm. The ionizer's volt-ampere characteristics in various modes were obtained, and its efficiency was calculated. The intensity or efficiency of air ionization is defined by the magnitude of the stable concentration of ions generated per unit volume inside the building during continuous ionizer operation. The magnitude is determined by the magnitude of the voltage across the discharge electrodes, the discharge distance, and the electrode design.

To adjust the voltage in the circuit diagram of the stand, an autotransformer (TV1), transformer (TV2), corona discharge electrodes (KE), grounded electrode (e.y.e.), control and measuring devices are connected to obtain the main characteristics of the ionizer in different modes and determine its efficiency. Microammeters are protected from emergency modes by dischargers (R) attached in parallel to the measuring devices (Figure 2). According to preliminary results, a corona discharge in the "needle-ring" discharge range was attained in our study. The angle of inclination of the needle and the radius of curvature of the edge determine the electric field strength at which the corona discharge begins:

$$E_0 = 30,3\delta(1 + \frac{0,298}{\sqrt{r_3 \cdot \delta}}) \quad (1)$$

here: E_0- electric field strength, V m

r_3- edge curvature radius of the discharge electrode, m

δ- air density.

The smaller the radius of curvature of the edge of the discharge electrode, the more efficient the discharge of the corona, and the edge of the tip of the needle depends on its material and heating technology. When the electric field voltage at which the corona discharge begins is studied at different discharge electrodes, it is observed that the ionization process begins at a relatively low voltage on the needles because the radius of curvature of the needle tip edge is less than that of the wire. The ionization process begins at 2.1 ... 2.5 kV on the needles, and a strong discharge occurs at 4-6 kV. In wires, the ionization process begins at a voltage of 5-6 kV, and the intensive discharge lasts at 10-15 kV.

The comparison shows that it is advisable to use ionizers with needle electrodes in fruit storage warehouses. For operation at relatively low voltages, ionizers use a small discharge distance and use a system of "needle-ring" electrodes. When the length of the needle corona discharge electrodes is 30-80 mm, the diameter of the cylindrical component, and the substance of the electrodes are all kept constant, the volt-ampere characteristics are not considerably affected. When multiple needle electrodes are discharged side by side, the ionization efficiency of each needle decreases, and as the discharge current increases, the number of air ions created and the volumetric concentration of ions in the air decreases. The ionization impact is reduced as a result of cross-shielding each other's fields, i.e. the quantity of air ions generated by each needle electrode is lowered. The electrodes of ionizers must be situated at an appropriate distance from each other in order for them to perform successfully. The ionization intensity created by a single needle increases first when the distance between the discharge electrodes increases to 35–40 mm, then stabilizes, and subsequently the ionizer's ionization intensity declines [8, 9].

The study's findings reveal that each discharge distance length has a certain critical voltage magnitude. There are two stages of the critical voltage, the first being the voltage U_0 at which the corona discharge begins and the voltage U_{kr} at which the maximum ionization intensity is provided. The quantity of ions in the air does not rise as the voltage increases, even though the corona discharge in the ionizer grows, due to mutual shielding of the needles' electric fields. With increasing ring diameter electrode diameter and distance between discharge electrode and grounded electrode in grounded electrodes, the corona discharge intensity decreases [10]. When the voltage at the discharge electrode is Ukr = 4-6 kV, the most efficient modes are available.

Depending on the design of the discharge electrodes, the volt-ampere characteristic of the ionizer has a varying slope. The most efficient operating modes of the ionizer are determined by the nature of the design dimensions and placement of the discharge and grounded electrodes. By determining the most suitable design dimensions of the electrodes and optimizing the operating modes of the ionizer, we obtain the maximum ionization effect of large buildings. Discharge distance is limited from below and above. If the electric field strength is sufficient to maintain a stable ionization mode on the low side, it is limited by the electrical strength of the air gap on the high side. At a small discharge distance, the normal operating mode interval of the ionizer will be small, i.e. the voltage between the starting voltage U_0 of the corona discharge and the voltage Ukr at which the maximum ionization intensity is provided will be close. The subsequent increase in voltage prevents the increase in ionization intensity due to cross-shielding in the electric field. The diameter of the rings on the grounded electrode and the distance between the discharge electrode and the grounded electrode are varied to alter the discharge interval distance (Figure 3). The electric field strength is determined by the potential electrode voltage for a given type-size electrode system. Based on the results of preliminary studies, we identify the main factors that affect the operating modes of the corona discharge electric ionizer. In the next step, we develop a plan matrix of the three-factor experiment and write it in the table (Table 1). To analyze the experimental options, we assume the following form of the regression equation:

$$У=a_0+a_1x_1+a_2x_2+a_3x_3+a_{12}x_1\cdot x_2+a_{13}x_1\cdot x_3+a_{23}x_3\cdot x_2+a_{123}x_1\cdot x_2\cdot x_3 \quad (2)$$

TABLE 1. The plan matrix of the experiment

l-x_1		H-x_2		U-x_3		y⁻,	Δy	Δ y^2	S_a^2
code	Fact	code	fact	code	fact	mA/m			
+	60	+	30	+	5	3.4	0.067	0.0045	1.24
+	60	+	30	-	3	1.9	1.43	2.05	
+	60	-	20	+	5	4.2	0.87	0.76	
+	60	-	20	-	3	2.5	0.83	0.69	
-	20	+	30	+	5	3.1	0.23	0.05	
-	20	+	30	-	3	1.8	1.53	2.34	
-	20	-	20	+	5	4.1	0.77	0.6	
-	20	-	20	-	3	2.6	0.73	0.53	

The coefficients of the obtained regression equation are determined as follows:

$$a_{ij}=\frac{1}{N}\sum_{i=1}^{N} x_{ij}^{N}\, y_i^{-} \quad (3)$$

where: N - number of experiments; y_i^{-} – is the average value of the optimization parameter in the i-experiment;
Determining the values of the coefficients of the regression equation, we obtain the following equation:

$$У=3+0{,}4x_2+0{,}75\,x_3+0{,}05\,x_1\cdot x_2+0{,}5\,x_1\cdot x_3-0{,}05\,x_3\cdot x_2-0{,}34\,x_1\cdot x_2\cdot x_3$$

This expression cannot fully represent the discharge field process because one of the key factors here is the lack of values of x1. For this reason, we conduct additional experiments by reducing the step spacing between the discharge electrodes, statistically process the results obtained, and obtain a new result. Table 3 shows the plan of subsequent experiments.

TABLE 2. The plan matrix of subsequent experiments and the results of statistical processing of the obtained results

x_1		x_2		x_3		y⁻,	y_N^-	$y_N^{o'rt}$	$S_{y_N^n}^2$
code	fact	code	fact	code	fact	mA/m			
+	60	+	30	+	5	3.4	3.45	3.49	0.075
+	60	+	30	-	3	2.05	2.04	1.93	0.013
+	60	-	20	+	5	4.2	4.13	4.11	0.04
+	60	-	20	-	3	2.6	2.45	2.55	0.0175
-	40	+	30	+	5	4.1	4.2	4.33	0.01
-	40	+	30	-	3	2.7	2.8	2.76	0.01
-	40	-	20	+	5	4.9	4.93	4.95	0.04

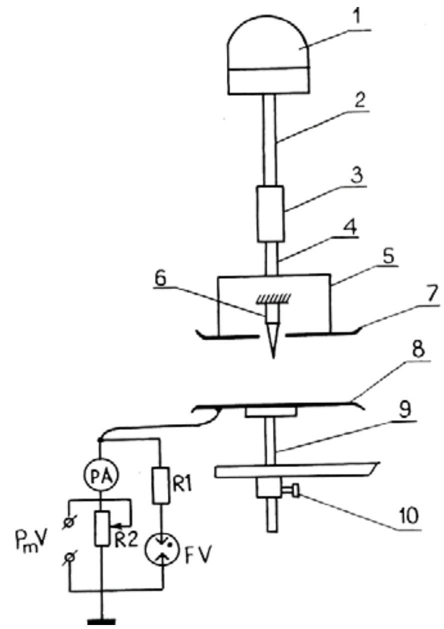

FIGURE 3. The influence of the length of the corona discharge needles on the corona discharge current (schematic stand)

Determining the coefficients of the resulting regression equation, we obtain the following expression (according to Table 2):

$$У=3,36+0,45x_1+0,38x_2+0,72\,x_3+0,04\,x_1\,x_2+0,02\,x_1x_3-0,026\,x_3\cdot x_2-0,02\,x_1\cdot x_2\cdot x_3 \quad (4)$$

To simplify the preparation conditions and installation, the conical angle of the needles' edge was considered to be 8o to limit the factors under investigation. Experiments were carried out on two different scenarios:

• The effect of the length of the corona discharge needles on the current of the stream-shaped and DC corona was studied;

• The streamer-shaped and DC corona discharge currents were investigated in relation to the distance between the corona discharge needles.

The experiments were automated, and the findings were recorded on a self-contained KSP-type potentiometer, due to the great number and reproducibility of the parameters sought.

RESULTS OF EXPERIMENTAL STUDIES

Using diagrams obtained on a self-contained potentiometer, the distance between the electrodes N and the length of the needles h (Tabel 3) and the distance between the electrodes N and the distance between the corona discharge needles (Table 4) nomograms describing the relationship were obtained.

The corona discharge needle-shaped electrodes have a considerable shielding effect as a potential plane to the discharge current emanating from the adjacent needle edges, as can be seen from the nomograms. When the electric field intensity remains constant, the size of the corona discharge current in the form of a stream from a single needle grows as the distance between the corona discharge needles and the grounded electrode increases. When h = 30 mm, for example, the corona discharge current changes as follows:

TABLE 3. The distance between the electrodes N and the length of the needles h

h, мм	10	20	30	40	50	60	70	60
$I_∂$, 10^{-6} A	18	28	37	42	49	54	58	60

If h = 10 mm:

TABLE 4. The distance between the electrodes N and the distance between the corona discharge needles

h, мм	10	20	30	40	50	60	70	60
$I_∂$, 10^{-6} A	16	21	23	24	26	27	28	28

With an increase in the length h of the corona discharge needles and an increase in the distance N between the electrodes, this feature of the corona discharge appears to be stronger. The maximum discharge current was found to be N/h> (1.6... 1.7), indicating that the discharge current increases as the length of the corona discharge needles increases to h > (1.6... 1.7) N. Because the length of the minimal dusting zone of the insulator should produce the maximum cleaning effect of dust - aerosol particles from the gas stream, this relationship necessitates precision in the calculation of the parameters and dimensions of the electrode system of insulators. Corona discharge electrodes - the number of needles should be determined by the magnitude of the discharge current's maximum density, which may be expressed as:

$$J = i_{1,\max} n / S, \tag{5}$$

where $\boldsymbol{i_{1,max}}$ is the maximum current generated by a single needle, A; $\boldsymbol{n}$- number of needles; $\boldsymbol{S = a \cdot b}$ – surface of the electrode system of the insulator, m^2; ***a and b*** – length and width of the electrode system, respectively, m.
The number of corona discharge needles is determined as follows:

$$n = (S / \ell^2) + \left[(a+b)/\ell\right] + 1, \tag{6}$$

where $\boldsymbol{\ell}$ – the distance between the needle axes when the discharge current stops.

These curves can be used to calculate and select the electrode system characteristics of the insulators at the outset. The findings of a study of aerosol particle separation from gas flow in stream-shaped corona electric fields show that the electrode system's parameters should be considered separately for "distance between corona discharge needles" and "distance between rows of needles" perpendicular to the purified gas flow in subsequent studies. The main advantage of the streamer-shaped pulsed voltage corona discharge is that the nature of the power effect of the electric field has been found to depend on the parameters of the supply circuit elements. This condition is important for various technological processes that take place in strong electric fields and allows precise adjustment of the processes performed, changing the parameters of the elements of the supply circuit.

CONCLUSIONS

a) Studies show that the stability of the corona discharge current of different shapes, depending on the parameters of the supply circuit, is observed up to a certain critical magnitude (pulse frequency, voltage, discharge distance, needle length).
b) The electrical strength of the discharge interval grows as the frequency of the pulses increases, and the discharge current increases as well.
c) The current of a streamer-shaped corona discharge is 2 times or more than the current of a corona discharge at constant voltage. The linear dependence of the corona discharge current on the voltage was determined. This linear relationship is disrupted as the frequency increases to a critical magnitude, and the stability of the discharge current is lost in subsequent increases in frequency.
d) Discharge currents in the system of electrodes in the form of "potential plane with corona discharge needles - grounded plane" depend on the parameters of the electrode system. The choice of the distance between the corona discharge needles should be determined according to the starting curvature points of the VA characteristics.
e) The law of variation of the discharge interval's electric field strength is the same as the law of variation of the magnitude of the voltage supplied to the discharge interval. In the electric field, the force exerted on the ionic particles varies in a similar way.
f) When the frequency is 200 s^{-1}, the reflected force, the magnitude of the charge, and its density are 2.31 times greater than the parameters of the constant voltage corona under similar conditions.
g) The findings show that the electric field of a streamer-shaped corona discharge is more efficient than that of a constant voltage corona discharge.

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