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Study on modeling of the air ionization process in the technology of long-term storage of fruit and grape

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Abstract. This article presents the results of modeling the process of air ionization in the technology of long-term storage of fruits and grapes in fruit storage facilities.Also was determined the main forces acting on ions in the ionization zone, in the volume of the fruit storage and on the surface of the processed product in order to establish the ionization modes and design the discharge gap of the ionizer. Based on the results of the research, the issues of the ionizer placement in the volume of the fruit storage have been resolved. The results of theoretical studies have been verified experimentally and the corresponding dependencies of the parameters of ionized air was obtained.

1. Introduction

In the Republic, special attention is paid to the development of infrastructure for processing and storage of fruit and vegetable products with the aim of uninterrupted supply of the population with fresh fruit all year round and reducing losses during long-term storage. For example, in 2017, more than 250 enterprises for the processing of agricultural products were built and modernized, more than 130 refrigerators with a total capacity of 85,700 tons of product [1, 2]. Various methods of storing fruits and vegetables are being established, the peculiarities of product storage technology using electrotechnological methods are being studied. To ensure the required quality of product processing, it is necessary to create certain parameters for the storage regimes of fruits directly on the surface of the product.Based on the results of theoretical and experimental studies of ionization technology, optimal modes of room ionization, parameters of ionized air, a scheme and device for ionization of air, and principles of control over the parameters of ionized air have been proposed [3,4].The main parameters of ionized air and the characteristics of the air environment of fruit storage have been analytically determined. The results obtained have been studied experimentally, verified and analyzed [5]. For air ionization in fruit storage technology, an electric ionizer with pointed electrodes has been developed, the main parameters of the device have been determined taking into account the technological requirements [6]

The model of the air ionization process consists of three fundamentally different elements: the ionization process in the discharge gap of the ionizer, the process of dispersion of air ions in the room, and the process of deposition of air ions on the surface of the processed product. Each of these processes requires a separate analysis. The process of air ionization in the discharge gap was studied experimentally and analytical expressions were obtained, however, the dispersion of air ions in the room and the process of deposition of air ions on the surface of the processed product were considered superficially or severally. Therefore, in our research, the ionization process was analyzed from the ion source to the processed product.

2. Research Methodology

Corona discharge electro ionizers operate on the basis of excitation and ionization in a highly inhomogeneous electric field on the surface of the electrodes of neutral molecules and air atoms at a sufficient electric field strength.A highly inhomogeneous electric field is obtained by two electrodes with different curvatures of the surface. One of the electrodes has a small curvature of the surface in the form of a tip, where an increased voltage is applied and is a source of ions and is called a discharge electrode. The second electrode is in the form of a plane or a large curvature of the surface and is grounded. To obtain a small size of the ionizer, the discharge and grounded electrodes are located in a sufficiently close distance. With sufficient voltage on the corona electrode (2.5-3 kV), the process of air ionization occurs in the discharge gap [5, 6].When storing fruit in an ionized air environment, electromagnetic forces directly affect biological organisms directly, without conversion to another type of energy, therefore, the technological process is performed with low energy consumption. Corona-discharge air ionizers are rationally used in the technology of long-term storage of fruits and vegetables. They are cheap, the processing technology is simple, easy to use and performed in various versions. Discharge electrodes can be installed on top of stacks of food crates in the form of antennas. At the same time, the quality of product processing will not be high, since air ions are distributed unevenly in the volume. For uniform ionization of air in large rooms, ionizers are installed in the ventilation system [7]. In this case, the ions are dissipated not only by electrostatic forces but also by ventilation. With the optimal distance between the ionizers, it is possible to ensure a uniform distribution of air ions and high-quality processing of the product throughout the entire volume [8, 9].

In large rooms, for example in industrial fruit storage facilities, the processed product is located at great distances from the ionizer. In order to obtain the effect of processing the product, air ions must reach the surface of the product. In this case, air ions pass through three different characteristic zones: the ionization zone on the discharge electrode, the zone of dispersion of space charges in the room, the zone of deposition and formation of an ion layer on the surface of the processed product.In the zone of ionization under the influence of an electric field of high intensity, air molecules acquire a certain charge. In this zone, the electric field is highly non-uniform and mainly electric forces act and the process will be very unstable. Along the lines of force of the electric field an electric wind formed under the influence of which ions are carried out of the ionization zoneIn large rooms, for example in industrial fruit storage facilities, the processed product is located at great distances from the ionizer. In order to obtain the effect of processing the product, air ions must reach the surface of the product. In this case, air ions pass through three different characteristic zones: the ionization zone on the discharge electrode, the zone of dispersion of space charges in the room, the zone of deposition and formation of an ion layer on the surface of the processed product.In the zone of ionization under the influence of an electric field of high intensity, air molecules acquire a certain charge. In this zone, the electric field is highly non-uniform and mainly electric forces act and the process will be very unstable. An electric wind is formed along the lines of force of the electric field under the influence of which ions are carried out of the ionization zone. The forces acting on the ions are determined by the strength of the electric field and the number of charges of the particles and are determined from the expression which is called the Coulomb force [10]:

$$F_k = E \cdot q \tag{1}$$

The particle is also influenced by the force of gravity:

$$F_q = mg \tag{2}$$

Due to the uneven distribution of ions in the volume, a particle with a dielectric constant is acted upon by an electric field force with an electric field strength E, which is determined from the expression:

$$F_E = 2 \ \tau \varepsilon_0 a^2 \frac{c-1}{c+2} \ \text{grad} \ E^2 \tag{3}$$

Depending on the size and shape of the particles, the resistance force of the medium acts on the ions. If we assume that the particle has a spherical shape, this force is determined from the following expression:

$$F_m = -6\pi\mu\vartheta\alpha^2 \tag{4}$$

It was noted that in order to evenly distribute ions in the volume of the fruit storage, the ionization system is combined with the ventilation system. The intensity of ionization and the distribution of ions in an enclosed space depends on discharge electrode voltage and the air flow rate

When determining the dependence of the quality of ionization on the operating and design parameters of the ionizer, preliminary information was given to the potential of the discharge electrodes and the dimensions of the discharge gap of the ionizer. The parameters of the outer zone of the corona discharge are determined by the joint solution of the differential form of the Gaussian equation and the dependences of the continuity of the current and the potential of the electric field and the current density and density of the space charge [11]. In modeling, the potential of the discharge electrodes is taken to be equal to the voltage of the electrodes, and the potential of the grounded electrodes is taken to be equal to zero, i.e.:

$$\varphi_{\text{p.э}} = U_{\text{p.э}}; \qquad \varphi_{\text{сyэ}} = 0. \tag{5}$$
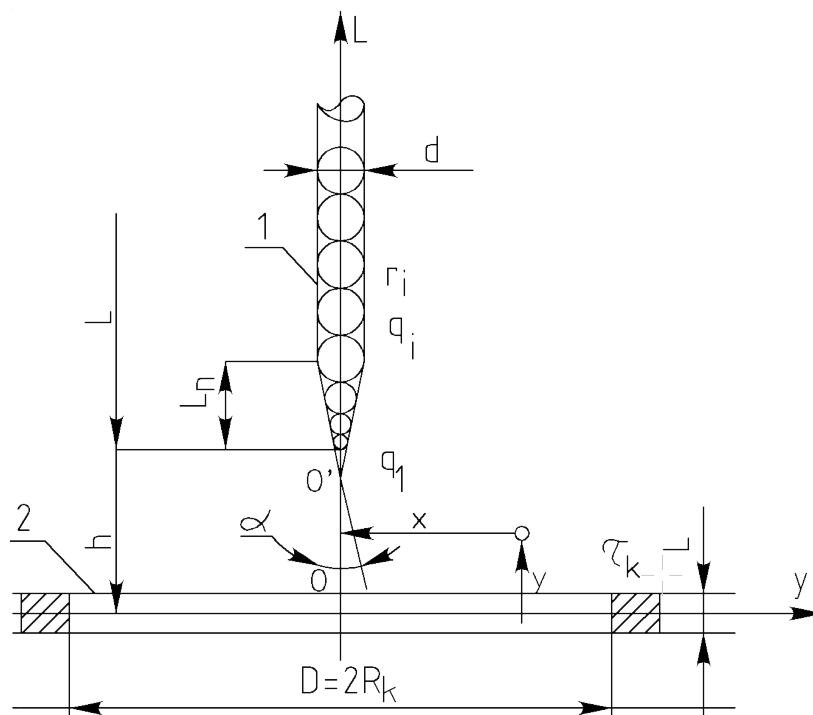
Figure 1. The design of the discharge gap between the needle and the ring: 1-needle, 2-ring, d-diameter of the pointed electrode (needle); D-is the diameter of the ring; ri -are the radii of the circles inscribed in the needle profile; qi- is the amount of a point charge located along the tip; k- is the amount of linear charge located along the ring; x, y-coordinates of calculated points in the electric field

Usually, when calculating the electric field of tip electrodes, the method of equivalent charges is used [12]. The discharge gap will be located between the needle and the ring cutout in the grounded plane, with the needle being perpendicular to the center line of the ring. The length of the pointed electrodes L, the distance between the tips $l_{1,}$, the radius of curvature of the tip's point r_3, the distance from the point of the tip h (Figure 1).The potential distribution in the discharge gap is represented as the sum of the potentials of point charges (q) located along the tip and the potentials of linear charges located along the ring (τ) (Figure 1). The equivalent of the potential of point charges is as follows:

$$\varphi = \frac{1}{4\pi\varepsilon_0} \sum\nolimits^{n} \frac{q_i}{\sqrt{(h+r_i-y)^2+x^2}}$$

(6)

here: $\varepsilon_0 = 8{,}85 \bullet 10^{-12}$

q_i- the amount of point charge
r_i - radius of the circumference inscribed in the profile of the needle
h-distance from the tip's point to the plane of the ring;
x,y- coordinates of the calculated points, where the potential of the electric field is determined.

Taking into account the condition $\varphi_p = U_p$, we compose a system of equations of the first order using Maxwell's formulas and obtain the following system:

$$\begin{cases} 4\bar{\kappa}\varepsilon_0 U_{\kappa} = \frac{q_{11}}{A_{11}} + \cdots + \frac{q_{1n}}{A_{1n}} \\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ \dots\ . \\ 4\pi\varepsilon_0 U_k = \frac{q_{l1}}{A_{l1}} + \cdots + \frac{q_{ln}}{A_{ln}} \end{cases}$$

(7)

3. Results

Having solved this system of equations, we obtain the distribution of the space charge density along the tip (2-fig). In this case, the parameters of the electric field increase sharply when the control point approaches the tip's point.
Now we are placing the equivalent linear charges along the circumference of the ring and equate its potential to zero: $\varphi_\tau = 0$. Since the radius of the ring is much larger than its thickness (R >> δ), the rings can be taken as a "circular torus". In this case, the potential of linear charges is represented as the potential of the charged axis:

$$\varphi_\tau = \frac{\tau}{2\pi\varepsilon_0} ln \frac{1}{r} + C$$

(8)

here: τ -the number of linear charges along the ring.
The potential of several concentric linear charges with a radius R_κ can be expressed as follows:

$$\varphi_\tau = \sum\nolimits_{k=1}^{n} \frac{\tau_k}{2\pi\varepsilon_0} ln \frac{R_k+r}{R_k-r}$$

(9)
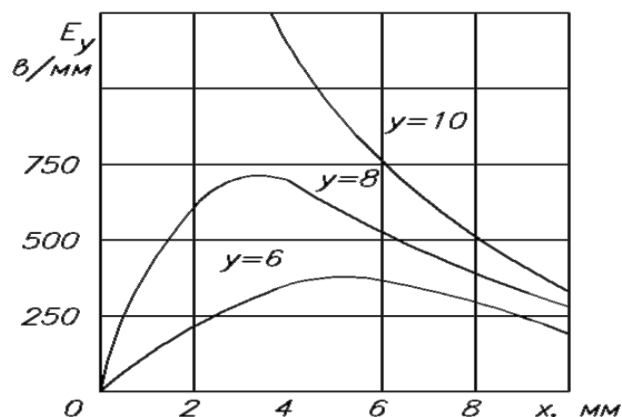
Figure 2. Distribution of the electric field strength in the discharge gap at different distances from the point of the potential electrode

The potential of an arbitrary point of the discharge gap is determined as the sum of the potentials of point and linear charges:

$$\varphi_{xyz} = \frac{1}{4\pi\varepsilon_0}\left[\sum^n \frac{q_i}{\sqrt{(h-y+r_i)^2+x^2+z^2}} - \sum^m \tau_k ln \frac{R_k}{y^2+(R_k-\sqrt{x^2+z})^2}\right]$$

(10)

The electric field strength in the discharge gap can be determined from the following ratio: $E = \frac{d\varphi}{dr}$

The distribution of the electric field strength in the discharge gap along the axial line of the tip has the form:

$$E_y = \left\{\sum_{i=1}^n \frac{q_i}{4\pi\varepsilon_0}\frac{h+r_i-y}{(h+r_i-y)^2+x^2+z^2} - \sum_{k=1}^m \frac{\tau_r}{2\pi\varepsilon_0}\frac{y}{\left(R_k-\sqrt{x^2+z^2}\right)^2+y^2}\right\}$$

(11)

We find the space charge distribution in the outer zone of the corona discharge electric field using the differential form of the Gauss equation:

$$\nabla^2\varphi = -\frac{\rho}{\varepsilon_0},$$

$$\rho = \frac{1}{4\pi}\sum_{i=1}^n q_i[(h+R_i-y)^2+x^2]^{-\frac{3}{2}}$$

(12)

Also, taking into account the an expression for the concentration $n = \frac{\rho}{e}$ expression of the formula, in the final form we can write of the space charge of the room in the following form:

$$n = \sum_{i=1}^n \frac{q_i}{4\pi e}[(h+R_i-y)^2+x^2]^{-\frac{3}{2}}$$

(13)

here, e - electron charge.

The density of the pointed electrodes is one of the factors of the intensity of air ionization. The most effective ionization mode is obtained when their density is 150-474 pcs / m2. In this case, the length of the tip also depends on the distance between them. In turn, the distance between the needles depends on the length of the discharge gap [13]. The density of the tip electrodes is limited by the effect of mutual shielding of the electric fields of the tips. The mutual screening of the electric fields of the points, apart from the weakening of the ionization intensity, also affects the ion flux in the volume.[14].
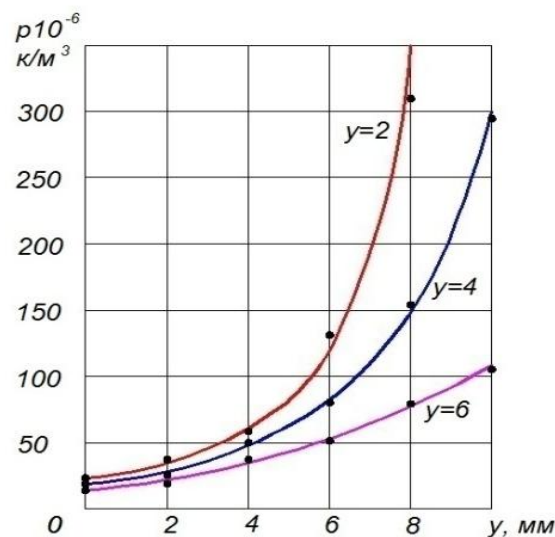

Figure 3. Experimental curves of the distribution of the space charge density (ρ) in the discharge gap
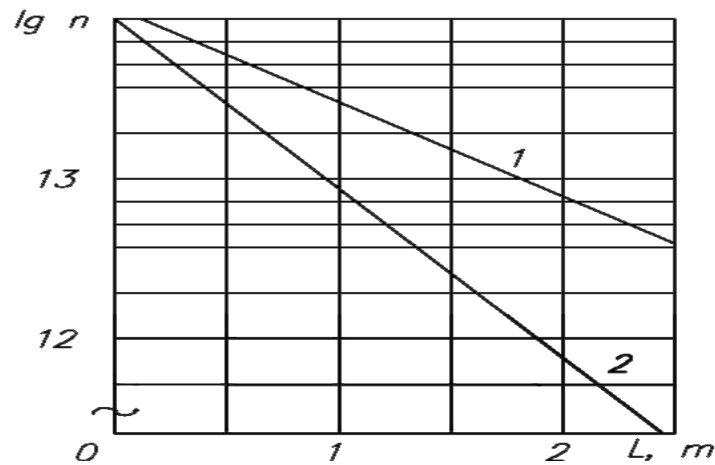
Figure 4. The distribution of the space charge along the length of the premises [8]

Sh. Muzafarov was engaged in the determination of the design parameters of the tip discharge electrodes and their arrangement at our institute; he used ionizers for air purification and for ozonation [15,16]. It has been proven that the electric corona charge effectively cleans the air from pollution, especially from fine dust. In the studies, various power sources were used: a positive and negative direct current source, a pulsed alternating current source of industrial and increased, for each case the optimal parameters were determined.   Based on the results of the analysis, we studied the features of the technology of long-term storage of fruits, the processes occurring in storage products, sources of product loss, the effect of air ions on fruits, optimal air ionization modes, the main parameters of the corona-discharge ionizer which provides the requirements of the air ionization technology of fruit storage. The results of theoretical and experimental studies were verified directly in production conditions.

The analytically obtained results ρ ,, E, were verified experimentally, which are shown in Figures 3 and 4. Thus, with a voltage across the discharge electrodes of 2.8-6 kV, with a discharge gap of 25-40 mm in the volume of the room, we obtain the space charge density within k /, and the volume concentration of ions within ion / [17]. Based on the research results, the optimal design parameters of the ionizer and their arrangement along the room were determined. If the ionizers are at a distance of 2 - 2.5 meters from each other and the ionization process is performed together with ventilation, the uniformity of the distribution of ions in the volume is within 85 - 87% [18]. Based on the results of experimental studies, the distribution of the potential and the electric field strength and the concentration of ions in the 6-volume were obtained (Figure 5).
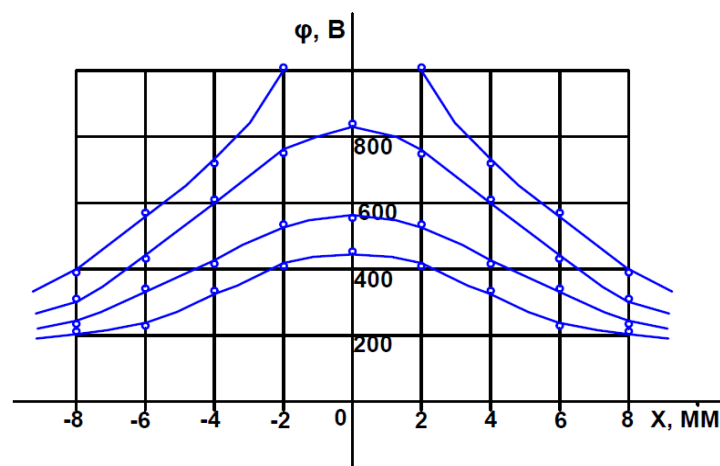
Figure 5. Distribution curves of the electric field potential of the corona discharge

The distribution of the main parameters of the electric field of the corona discharge in the outer zone of air ionization is obtained by the same method.In this case, the parameters of the electric field increase sharply when the control point approaches the discharge electrode, with the coordinate x = 0; y = 10. The results obtained are the basis for the development of an air ionization device for closed rooms. As a result of the research, the following conclusions were gotton

4. Conclusions

a)   Application of ionization using a corona discharge in various technological processes is due to the simplicity and cheapness of the method, it is performed by low energy consumption and control versatility. The operating parameters of air ionization depend on the design parameters of the ionizer and the characteristics of the power source. With analytical and experimental determination of the parameters of the electric field of the corona discharge and ionization of air, the errors of the results do not exceed 3 ÷ 5%. At a density of space charges in the outer zone k / the volume concentration of ions is within the limits of ion /.

b)   Ionized air in a closed room moving from the ionizer to the surface of the processed product passes through three characteristic zones: the ionization zone, the dispersion of the volume charge in the volume and the zone of coverage of the product surface with an ionic layer. The parameters of these zones differ sharply from each other and require separate consideration.

c)   In the technological process of ionization, air ions are affected by the electric field strength of the corona discharge, the own weight of the ionized particle, the electric field strength of the space charge, the medium resistance force and the electric field force of the ionic layer of the product surface.

d)   The parameters of the electric field of the corona discharge have a sharply variable character of change and have a non-stationary form; therefore, all results should be confirmed by the data of experimental studies.

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