Control over parameters of ionized air

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Abstract. The article presents the results of the study of the parameters of ionized air, measuring tools, it analyzes the processes and errors of measuring the potential corona discharge field, the volume concentration of air ions, and the density of space charges in the object. The dynamics of air ions in the measuring system, the conditions, and associated errors were studied. The obtained results are considered from the point of view of the application in fruit storage. The aspiration methods were used, the measurements were performed in the ionization zone - in the ionizer, in the volume of the room, and on the surface of the processed product. A simplified design of ionometers for air ions was used in studies for measuring the volume concentration of air ions. They work on the principle of discharge of an aspiration system and are convenient for indoor use.

1. Introduction
To obtain the expected effect, when using ionized air in various technological processes, it is necessary to correctly set the processing dose and uniformly treat the product. According to the technological requirements for the storage of vegetable feed, the optimal doses of product processing during its long-term storage were determined [1]. In this paper, the issues of monitoring the parameters of ionized air in fruit storages are considered. To measure the volume concentration of air ions, a simplified system for measuring air ions of the aspiration type based on the discharge principle was used.

Air is ionized by a corona discharge ionizer. The parameters of ionized air were determined analytically [2]. A non-contact method has been developed for an experimental study of the parameters of ionized air. The results are compared with theoretical data and the ionized air parameters distribution in large premises is obtained.

2. Methods
The research methodology is based on a review of existing and applied control methods at irrigation pumping stations, comparative analysis, and comparison of these methods, taking into account the operating conditions of irrigation pumping stations.

When comparing control methods, the operational data of the Kizil-Bayrak, Ulugbek II, Ittifok, Navoi, Turkiston, and Teshiktash-1 pumping stations were taken. Kizil-Bayrak, Ulugbek II, Ittifok, Navoi and Turkiston pumping stations have overestimated technical performance compared to the actual required. Teshiktash-1 pumping station has very different water consumption and water supply schedules. When processing data, standard statistical techniques and programs were used.

The key parameter of ionized air is the volume concentration of air ions (n). The volume concentration of air ions can be measured directly by an air ion counter or indirectly by ion current. The simplest way to measure the volume concentration of air ions is the open collector method. The
ionizer's current density is measured. The ion current flowing through the measuring collector \( I_i \) and the collector surface area \( S \) determine the volume concentration of air ions. The ion current of the collector \( I_i \) is measured by a microammeter or a sensitive galvanometer. The volume concentration of air ions is calculated from the following expression [3,4,5]:

\[
j = 6 \frac{I_i}{S} \quad j = n \cdot k \cdot E
\]

where:
- \( j \) is the current density, mA/m\(^2\)
- \( I_i \) is the current strength according to the galvanometer reading, mA
- \( k \) is the mobility of air ions, \( k = 2.1 \cdot 10^{-4} \text{ m}^2/\text{B} \cdot \text{c} \)
- \( E \) is the electric field strength, \( \text{B/m} \).

More accurate results can be obtained using air ion counters, but they are expensive and not always available. The volume concentration of air ions is often measured by a simplified scheme of aspirator type ionometers. In this case, the test air is sucked through the measuring capacitor (Fig.1) [6,7,8]. One of the electrodes of the measuring capacitor has a certain potential, and the second is grounded. Air ions having mobility less than the critical mobility of ions are held by a measuring capacitor and their current is detected by a sensitive electrometer.

![Figure 1. Measuring of volume concentration of ions by a cylindrical metering capacitor:](image)

1 is external cylinder, 2 is internal cylinder, 3 is dielectric 4 is guide ways, 5 is fan

The magnitude of ion current also depends on the air flow rate through the measuring capacitor, the capacitance of the capacitor and the voltage of the potential electrode of the measuring capacitor and is determined from the following expression:

\[
k = 8.85 \cdot 10^6 \frac{Q}{C \cdot U}
\]

where:
- \( C \) is the capacitance of the measuring capacitor,
- \( U \) is the voltage of the potential electrode of the measuring capacitor,
- \( Q \) is the quantity (flow rate) of the air flow through the measuring capacitor.

The volume concentration of air ions (n) and the ion mobility spectrum (k) are determined from the voltage values of the potential electrode of the measuring capacitor, the air flow rate through the measuring capacitor, and the saturation current of the capacitor.

To measure the volume concentration of air ions, the counters of various designs have been developed. These devices make it possible to measure air ions at ion mobility from \( k=8 \cdot 10^{-4} \) to \( 10^{-10} \)
\( m^2 \cdot B^{1} \cdot c^1 \) and a volume concentration of air ions from \( n = 108 \) to \( 3.16 \cdot 10^{15} \) ion \( \cdot \) m\(^3\), which is acceptable to control the parameters of large electrical ionizers [9, 10]. In our studies, the simplified designs of ionometers were used. Such devices operate on the principle of aspiration, are simple in design and convenient in operation.

During air ionization, ozone is formed on the surface of the potential electrode of the ionizer with sufficient electric field strength; it reduces the marketable and dietary qualities of the product [11, 12, 13]. Ozone rapidly decomposes into one- and two-atomic oxygen and the oxygen accelerates the intensity of respiration and metabolic processes, resulting in increased product loss. Besides, the pungent odor of ozone, at a sufficient concentration, removes the aroma and natural smell of fruit. The product loses its natural color and marketable quality and becomes inconsumable.

The complexity of the processes occurring in a corona discharge electric field and the rapid change in the parameters of the electric field create difficulties in the analytical determination of their relationship. To build a model of corona discharge electric field process is a rather complicated task. Therefore, to study the processes of the corona discharge field, more attention should be paid to experimental methods. Results obtained in theoretical studies should be confirmed by experimental studies, only then a mathematical model can be built and applied in practice.

Experimental studies provide reliable results on the parameters of the electric field. The sharply varying pattern of change in electric field parameters of the corona discharge does not allow the use of contact measurement methods since this changes the configuration of the electric field; accurate data can be obtained only by non-contact measurement methods. The most common methods are the aspiration and probe methods. Probe methods are more acceptable for studying the processes in the discharge gap of an ionizer. The results of probe studies of the corona discharge field were given in our previous publications [14,15,16]. The probe introduction into the electric field violates the configuration of the electric field. With the aspiration method, the air under consideration is sucked through the measuring capacitor, and the electric field parameter of the space charge is determined by the charging or discharging current. When studying the parameters of ionized air flow from the source to the processed product, the non-contact aspiration method ensures a minimum of errors acceptable for technical studies. The method allows control of the distribution of air ions (n) volume concentration, electric field potential (\( \phi \)), space charge density (\( p \)). The method was adopted to study the electric field of a unipolar corona discharge of any configuration but is applied mostly for an electric field with point electrodes [17, 18, 19].

The screen of the measuring capacitor allows maintaining the shape of the electric field, reducing measurement errors when introducing the gauge into the electric field. The key includes a measurement circuit, the discharge current of the measuring capacitor is measured with an ammeter. The known capacitance of the measuring capacitor determines the volume concentration of air ions, the potential of electric field, and the density of space charge in the test premises (Fig.2). Based on the research results, the distribution curves of the electric field parameters are plotted.

In studies, the adopted electroionizer has point discharge electrodes that are perpendicular to the plane of the grounded electrode. The grounded electrode has cutouts in the form of a circle with a
diameter of 20 mm along the axis of which the point electrodes are located perpendicular. The tips of point electrodes are located at a distance of 10 mm from the plane of the grounded electrode (Fig.3). The experimental camera-measuring device records the parameters of the electric field along all coordinates of the electric field. The tip of the point has coordinates $x=0; y=0$.

![Figure 3. Design of the discharge gap point-ring:](image)

1 is needle, 2 is ring grounded electrode, $d$ is diameter of the needle; $D$ is diameter of the ring; $r_i$ is circle radius inscribed in the profile of the needle stem; $q_i$ is point charges located along the point electrode; $\tau_k$ is line charges located along the ring; $x, y$ are coordinates of the calculated points of the electric field

3. Results and Discussion

When determining the parameters of the electric field of the corona discharge and the space charge of air ions, the characteristic of the measuring capacitor is used; the electric field strength, the density of the space charge, the mobility of air ions and the distribution of the electric field potential in the volume are determined. The results are the basis for the development of electric ionizers for indoor premises. Knowing the basic parameters of the ionizers, we can correctly select and optimally arrange them in the volume of the premises. Ionization modes are determined from technological requirements.

When studying the dynamics of ions motion, the parameters of ionized air are controlled from the ionizer to the processed product. Here three different electric fields are observed: the discharge gap of the electric ionizer, the field of the space charge of air ions, and the electric field of the surface of the processed product. In the discharge gap of the electric ionizer, electric forces prevail; in the premises - the strength of the electric field of space charge of air ions dissipation, and on the surface of the processed product - the electric field of space charge of air ions and the electrophysical properties; the shapes and sizes of the stored raw materials are also significant. The electric field has a maximum value in the ionization zone and decreases with the distance from the ionizers.

The efficiency of air ionization depends on the volume concentration of air ions in the location area of the processed product and the uniform distribution of ions throughout the storage chamber. To solve this problem, the nature of air ions motion from the ionizer to the processed product was studied. The studies were carried out under production conditions in the fruit storage of the Syrdarya region farms. Besides, the collaboration continues with the department of processing and storage of the Institute of Horticulture, Viticulture, and Winemaking named after M. Mirzaev.
Air ions are formed in the electric field of a corona discharge and are quickly recombined, but at a sufficient intensity of air ionization in the room, a space charge of a certain density is formed. The goal of air ionization storage technology is to ensure that the ions are uniformly distributed throughout the volume of the premises and reach the surface of the processed product. On the surface of the product the air ions create an ionic layer that affects the metabolic processes on the surface of the product.

![Figure 4. The path of air ions from the ionizer to the processed product](image)

Air ions generated during the corona discharge process in a room create a cloud of air ions and move from the ionizer to the processed product (Fig.4). The uniformity of air ionization depends on the power and number of ionizers, the distance from the ionizers to the processed product. To improve the uniformity of air ionization in large premises, the ionizers are equipped with fans or the ionizers are installed in the ventilation system. Studying the dynamics of ions motion inside the room, we can determine the distance between the ionizers and arrange them in the storage chamber. The dynamics of ions motion in the premises is determined by the forces acting on air ions. The highest dynamics of ion motion is observed in the ionization zone, between the discharge and grounded electrodes. The ions emitted from the ionizer form a cloud of air ions with a certain volume concentration of ions (n) and density of space charges (ρ). Here, the strength of volume dispersion of air ions prevails.

In the ionization zone of the ionizer, charged particles are affected by electrostatic forces:

\[ F_E = Eq \] (3)

The force arising from non-uniform distribution of electric field strength is also significant:

\[ F_e = 2\pi \varepsilon_0 a^3 \frac{q}{\varepsilon^2} \text{grad} E^2 \] (4)

Since the size of the charged particles is small, the force arising due to the non-uniform distribution of the electric field strength is very small relative to the electrostatic forces of the corona discharge field, at an electric field intensity \( E > 1kV/sm \), their ratio is approximately \( F_e = 0.01F_E \), therefore, the force arising due to the non-uniform distribution of the electric field intensity \( F_e \) is not taken into account in calculations. The calculated data were verified by experimental studies, as a result of which the pattern of distribution of the electric field potential and the density of charges of air ions in the discharge gap “point-ring” was obtained (Fig.5).
Ventilation forces are taken as an external effect of the environment on the air ions flow in the premises. The magnitude of this force acting on charged particles depends on the Reynolds number of the medium and is determined from expression:

$$ R_e = \frac{v l}{\gamma} $$  

(5)

here:  $v$ is the velocity of charged particles motion in air ions flow;  
$l$ are the characteristic sizes of charged particles; 
$\gamma$ is the kinematic viscosity of the medium.

At air pressure $P = 1.013 \cdot 10^5$ Pa and ambient temperature $t = 0^0C$, the kinematic viscosity of the medium is $\gamma=0.136 \cdot 10^{-4} \text{m}^2/\text{s}$.

During air ionization, a charged particle has one electronic charge and small size, and the Stokes force acting on a spherical particle is determined from the following expression:

$$ F_e = -6\pi \mu a \gamma $$  

(6)

here:  $\gamma$ is the kinematic viscosity of the medium.

If a very small particle is in the shape of a ball, the Reynolds number can be taken equal to:  
$R_e < 0.5$. To obtain a more accurate result, we can use the following expression:

$$ F_e = -6\pi \mu a \gamma \frac{1}{1+A_k l_m / a} $$  

(7)

here:  $l_m$ is the mean free path of a charged particle depending on the kinematic viscosity of the medium.

At air pressure $P = 1,013 \cdot 10^5$ Pa, and ambient temperature $t = 20^0C$, the mean free path of a charged particle depending on gas kinematic viscosity is:

$$ l_m = 0.942 \cdot 10^{-5} \text{sm}; $$

$A_k$ is determined depending on the surface state of the particle, for a smooth surface it is $A_k=0.86$.

If the shape of the charged particles is assumed to be an ellipsoid, the resistance of the medium is minimal and the scattering of results of calculation and experimental studies do not exceed 10%. In this case, the velocity of the particle, the resistance of the medium to the ionized air flow, the ion
propagation distance and the forces acting on air ions are under control. At charged particles motion, the forces acting on them are proportional to the sum of the acting forces and the mass of charged particles. In the ionization zone of the ionizer, mainly electric forces act on the ionized air flow, and in the premises the ventilation forces have a greater influence. If the forces acting on the ion flow and the resistance forces of the medium are equal, the dynamics of air ions motion becomes stable, that is, they move at a constant velocity.

In this case, the ion velocity takes the following form:

$$v = \frac{E_q (1 + A_k \ln \frac{l}{a})}{6 \mu \alpha \pi}$$ \hspace{1cm} (8)

To determine the distribution of volume concentration of air ions in the room from the ionizer to the processed product, a calculation experiment was conducted. The product was at a distance from 1 to 2.5 meters. According to the results of the experiment with fivefold repetition, the following empirical expressions were obtained:

$$N = e^{32.1803 - 10.9888}$$ \hspace{1cm} with ventilation \hspace{1cm} (9)

$$N = e^{32.1803 - 1.8244}$$ \hspace{1cm} without ventilation \hspace{1cm} (10)

Using these expressions, the pattern of air ions distribution in the fruit storage volume can be obtained when combining ionizers with a ventilation system and without the ventilation system (Fig.6).

Comparing the calculated values of the parameters of the ionized air flow with the measurement results we can draw the following conclusions:

4. Conclusions
1. The parameters of the corona discharge field have a sharply varying pattern and are non-stationary, therefore all theoretical data should be confirmed by experimental studies. Non-contact methods are accepted for the experimental study of the parameters of the electric field of a corona discharge, and the most effective of them is the aspiration method.

2. In the aspiration method, the parameters of ionized air, such as the volume concentration of air ions, the density of the space charge, and the electric field potential are determined to take into account the characteristics of the measuring capacitor and the flow rate of air ions. The obtained
research results allow us to state the modes of air ionization in large premises and to develop the product processing modes for long-term storage.

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