Interaction of corona discharge plasma with a disperse media

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Abstract. Results of experimental research on influence of corona discharge on the disperse medium - clay are described. The role of the corona discharge influence in the change of its electrical conductivity is revealed. Features of changes in the concentrations of certain chemical elements under the influence of the corona discharge on the clay have been revealed.

1. Introduction

Studies of gas discharges influence on the disperse medium - soil have been carried out since the mid-19th century [1–5]. They study the processes affecting the properties of the soil, changing its structure; chemical, mechanical, electrical and transport changes in the soil and their effect on plant growth. Recently, interest in the influencing of plasma on soil has emerged from the point of view of gas discharges using possibility in missions to Mars and Venus, where it is necessary to create or activate disperse medium of soil and its components for stimulating plant growth in greenhouses [6,7].

At present, aspects of the impact of the discharge plasma created in the atmosphere above the Earth surface on the disperse media - soil and clay remain poorly understood. It makes it difficult to analyze the possibility of discharges use in space. Therefore, this article is devoted to the study of the corona discharges plasma influence on the disperse medium - clay - the component of the soil, since corona discharges are the simplest in realization and low power.

Studies of the glow discharge plasma, close to those at the tip of the corona discharge [8,9], show that such a plasma contains a large number of positive and negative ions, as well as neutral particles that were absent in the air before plasma exposure. These ions can quickly transform into NO₃⁻. Calculations of the humid airplasma [9], have shown appearance of ions and components, which can affect the course of transformation processes into the NH₄⁺ in the clay. Calculations [10] of the ozone formed under the action of both positive and negative corona showed its high concentrations. Ozone can also participate in modification of physical and chemical properties of the clay.

These calculations show the promise of gas discharges using over the disperse medium - clay surface in order to improve its agricultural attractiveness [11,14].
2. Experimental technique

From the point of view of the discharge type choice, one should consider the corona discharge. It is easy to operate. It introduces ions and molecules realized in the discharge in air into the surface of the clay layer. It does not bring the electrodes material into the clay. By changing the positive to the negative corona, one can investigate the effect of both positive and negative ions on the clay separately. In addition, the corona discharge models the effect of ion fluxes in normal atmospheric conditions and during thunderstorms on the clay covered areas of the Earth.

The corona discharge is a low-current, low-luminous discharge that appears in the vicinity of the conductor tip [15]. The corona discharge [15, 16] in air occurs at room temperature and atmospheric pressure at a distance of several centimeters. The design of the corona discharge devices can be different – one and multi-electrode devices, corona discharge on long wires which can activate large areas.

The scheme of our simplest experimental device is presented in Figure 1. It consists of a cell filled with clay and an electrical circuit.

![Figure 1. Scheme for creating of a corona discharge: 1 – cell, 2 – sample, 3 – anode, 4 – stand, 5 – cathode, 6 – power source](image)

The top electrode is a needle or a set of needles up to 30 pieces with a diameter of 2 mm (with a tip radius of \( \sim 0.4 \) mm). They are placed 5–15 mm above the surface of the sample. The discharge is powered from an adjustable source with an emf \( E = 0–30 \) kV and an internal resistance of \( R = 100 \, \text{M} \Omega \). In this case, the current and voltage drop across the discharge gap are recorded.

The cuvettes are made of metal or dielectric. The distance between the sample surface and the top electrode ranged from 10 to 30 mm. The cuvette acted as the electrode of opposite polarity. It was located directly under the upper electrode. Processing of the clay sample was carried out within 1-10 minutes.

In Figure 2 we represent our multi-pin high voltage corona discharge device with the voltage in the range 5-10 kV and current up to 100 \( \mu \)A.

In Figure 2 one can see a device in which one can vary a distance between a treated sample and a set of needles connected with the high voltage electrode. The dish under the needles is filled with the clay. A typical photo of the clay layer in the dish (7 cm in a diameter) after the influence of the corona discharge see in Figure 3. One can see effective areas of the plasma impact under the needles.

For research a clay from the Selivanovsky district, the Vladimir region, Russia, was used. Typical Photo of the clay particles is presented in Figure 4.
Figure 2. An appearance of the multi-pin electrode

According to the classification [11], the clay is lightweight. The granulometric composition of the original clay: coarse and medium sand (1-0.25 mm) – 1.76%; fine sand (0.25-0.05 mm) – 9.80%; dust is large (0.05-0.01 mm) – 27.61%; medium dust (0.01–0.005 mm) – 1.20%; fine dust (0.005-0.001 mm) – 10.81%; mud (< 0.001 mm) – 38.82%; The sum of particles with a size of < 0.01 mm is 60.83%.

Studies of the physicochemical properties of the clay showed that: the cation exchange capacity is: 31.5 mg-Eq/100 g; degree of saturation with bases: 83.8%; cation content (mg-Eq/100 g): Ca – 16.6; Mg is 7; K – 1.9; Na is 0.9. In addition, the mineralogical composition of the clay fraction of the studied clay was determined: the content of the montmorillonite group is 35%; the content of the group of hydromicas (illite) – 30%; kaolinite + chlorite groups – 28% of the total fraction.

Determination of electrical conductivity in the clay pastes [13]. This method was applied to all samples. Samples were brought to the same humidity, dilution 1:1. The measurement was carried out by 4-electrode installation, Landmapper-ERM. The sample was placed in a cuvette, so that the soil completely filled it, then the electrodes were connected and measured, setting
Figure 3. Typical photo of the clay in the dish after plasma influence

Figure 4. Typical microscope photo of clay components
the desired mode on the device.

- Particle size distribution by the Analysette 22 comfort laser diffraction analyzer. It measures particles ranging in size from 0.01 to 1250 microns. The device consists of a measuring unit with a laser and a moving cell and from a sample preparation unit with an ultrasonic bath (with a micro-aggregate analysis, ultrasonic treatment is not performed when the sample is applied).

- Determination of pH, the content of NO₃ and NH₄ \[12\]. The determination was made by a potentiometric method, using ion – selective electrodes. The device for determining these properties – Expert 001, a liquid analyzer \[12\].

- Determination of macro elements nutrients and microelements \[12\]. The determination of the mass fraction of the soil macro and microelements was carried out by inductively coupled plasma using an Agilent ICP-MS 7500 mass spectrometer.

3. Experimental results

Below results with visible differences of the processed samples from the control are presented in Table 1. We indicate the clay layer width, height of needles over clay surface and time of processing. The amount of electrical energy supplied to the clay surface was calculated by the formula: \( E = U \cdot I \cdot T \), where \( U \) is the voltage of the discharge, \( I \) – electric current in it, \( T \) – time of the discharge influence. Typical values of voltage and current were \( U = 8-10 \) kV and \( I = 240-260 \) µA. The exposure time ranged from 1 to 10 minutes.

| Sample (characteristics of processing conditions) | pH of an aqueous suspension (1:2, 5) | Electrical conductivity of suspension (\( \mu \)S/cm) | Content of nitrates (NO₃) in clay solid phase, mg/10 g | Content of ammonium (NH₄) in clay solid phase, mg/10 g | Inputted energy \( I \cdot U \cdot t, J \) |
|-------------------------------------------------|---------------------------------------|----------------------------------------------------|-------------------------------------------------|-------------------------------------------------|---------------------------------------------|
| Control (clay not processed)                     | 6.75                                  | 102                                                | 0.067                                           | 0.040                                           | 0.0                                         |
| layer 5 mm; needle height 5 mm; t = 10 min.      | 6.11                                  | 202                                                | 0.76                                            | 0.46                                            | 926.7                                       |
| layer 5 mm; needle height 7 mm; t = 10 min.      | 6.10                                  | 280                                                | 0.635                                           | 0.282                                           | 1143.7                                      |
| layer 10 mm; needle height 5 mm; t = 10 min.     | 5.95                                  | 148                                                | 0.44                                            | 0.16                                            | 895.3                                       |
| layer 10 mm; needle height 10 mm; t = 2 min.     | 6.27                                  | 133                                                | 0.257                                           | 0.119                                           | 294.5                                       |
| 10 mm layer; needle height 10 mm; t = 5 min.     | 6.73                                  | 245                                                | 1.0                                             | 0.72                                            | 669.5                                       |
Preliminary conclusions on the experimental results are

- The clay from the gas phase perceives the flow of charged particles in the ion form. This is evidenced by the increase in the electrical conductivity of the aqueous suspension (see Table 1). Under the negative corona, ions entering the clay from the plasma (gas phase) have a negative charge.

- Plasma ions interaction with clay is a decrease influences its acid properties. (The pH of the aqueous suspension is shifted to a more acidic region (see Table 1). The nature of this phenomenon requires additional analysis.

- The process of acidification of the clay can go in two possible directions. Firstly, ozone, which is formed as result of the negative corona discharge plasma action on clay, has an oxidizing effect. Natural clay, although in small quantities, contains organic matter. Subjected to ozone oxidation, organic matter forms acidic groups. These groups can lead not only to a shift in the reaction of the medium (pH), but also to an increase in electrical conductivity. Secondly (less likely) is the exchange reactions as result of exposure to the negative corona. Exchange aluminum fixed on the surface of clay particles enters the diffuse layer of the colloidal micelle counterions. The action of aluminum ions is similar to the action of hydrogen ions, enhancing acidic properties.

- It is noteworthy to stress the increase in the concentration of nitrogen mineral forms in samples treated by the negative corona. However, the mechanism is apparently different for nitrates and ammonium. A positively charged ammonium ion was initially fixed on a negatively charged surface of clay particles (a layer of fixed counterions). When exposed to plasma, the ammonium ion becomes free, acquires mobility.

- A negatively charged nitrate ion initially could not be a part of the colloidal micelle. It could appear only from the gas, as result of the discharge plasma action, during the decay of the molecular forms of nitrogen and oxygen.

- The severity degree of the processes occurring in clay as result of processing it by the negative corona is determined by the experimental conditions (a layer of clay and supplied electrical energy).

- The greater is inputted energy and the thinner is the sample the greater is obtained conductivity and greater is content of nitrates and ammonium.

4. Conclusion

The article shows that the action corona discharges leads to a significant change in clay characteristics such as electrical conductivity, particle size distribution, macroelement composition, and an increase in the nitrogen-containing components NH$_4$ and NO$_3$, which can lead to improvesoil properties determining plant growth. Ionization and dissociation of air molecules when exposed to the corona discharge leads to a change (increase) in the conductivity of clay.

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