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# Study of electrical aerosol spreading in closed agricultural premises

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***Abstract*— Relevance of this research centers around the need to improve the methods of electro-aerosol disinfection and disinsection of air and surfaces in closed livestock buildings and poultry houses. During this research, the tasks were set to develop a mathematical model of electrical, dynamic and kinetic processes that occur during electro-aerosol treatment of agricultural premises which allow identifying the main patterns of spreading and deposition of electro-aerosol cloud. As a result of research, a mathematical model of spreading and deposition of electro-aerosol cloud in closed agricultural premises was obtained. The laws of electrophysical processes affecting electrical aerosol spreading were considered including the forces of electrostatic dispersion, gravitational settling and coagulation. The flow of electrical aerosol into the premises during working of electrical aerosol generator was considered taking into account air flow generated by it. Information mentioned in this article can be useful for researchers, graduate students, engineers involved in design, manufacturing and application of electrical aerosol disinfection technology.**

***Keywords*— electrical aerosol, electrical aerosol disinfection of agricultural premises, electro-aerosol cloud, electrostatic dispersion, gravitational settling, electrical aerosol coagulation.***

## I. INTRODUCTION

Modern industrial methods of keeping animals together with an increase in production intensity lead to favorable conditions for the spread of pathogenic microorganisms.

Pathogens develop in the bodies of sick animals and in the products of their vital and respiratory activities [7, 10]. Microorganisms form bacterial aerosol which spreads in livestock buildings and beyond them; it is settled on surfaces and gets in the respiratory system of animals. The spread of microorganisms in premises is generally influenced by convective air flow and microclimate parameters, such as humidity, temperature, and the presence of airborne dust. Air environment becomes a transport for microorganisms; the movement of air masses contributes to increasing microbial contamination level of enclosed space. In addition, pathogenic microorganisms, together with ventilating air flows, get into the air of livestock farms and spread throughout the surrounding area.

The intense spread of pathogenic aerosol can cause mass disease of animals and, as a result, lead to product losses and financial damage to enterprises. Therefore, the role of veterinary and sanitary measures for disinfection and disinsection of air and surfaces in premises significantly increases.

There are physical, biological and chemical methods of premises disinfecting. Physical methods include ultraviolet radiation, high temperature and ionizing radiation. The disadvantages of physical methods are the complexity of their application, high cost of equipment, superficial disinfection of equipment. Therefore, physical methods are used for the treatment of small premises. Biological methods are based on using living organisms - antagonists for the destruction of pathogenic microorganisms. Biological methods are currently in course of development; therefore, they are not widely applicable yet. Thus, at present, chemical methods are the most widely used ones for disinfecting livestock buildings.

Effectiveness of treatment with chemicals depends on the concentration of active substance in solution, on temperature and time of treatment. For high-quality treatment in actual practice, the following chemicals were found to be good: with stable bactericidal effect, suitable for the making aqueous solutions, with no corrosive effect on metal structures and equipment, with no smell, with no dangerous toxic effect on humans and animals.

Routine methods of premises treatment – spraying and washing – are laborious, require the preliminary setting of disinfection equipment, include large costs for disinfectants. Since the routine treatment method requires large amount of disinfectants, then these preparations, due to ventilation air flows and infiltration, partially move outside livestock building and have a polluting effect on the environment.

In modern treatment technologies, chemical agents are introduced into premises in aerosol form. Aerosol disinfection reduces the costs of disinfectants by 3 ... 5 times [7, 10, 11]. Together with the disinfection of surfaces, during aerosol treatment the disinfection of the air in premises [5, 7] is simultaneously performed.

Aerosol charging allows changing the whole technology of premises treatment. The essence of charging is to give an electric charge to aerosol particles. There are several ways of aerosol charging, i.e. using chemical, mechanical or thermal energy, ion charging by settling of ions on the aerosol, charging in electrostatic field.

Chemical, mechanical and thermal ways of charging are not widespread due to low energy efficiency. Ion charging is usually performed in corona discharge field. Settling of ions on aerosol particles occurs due to the diffusion of ions when they collide with aerosol particles. At the same time, both negative and positive charges can be obtained. To obtain high charges, aerosol particles should stay in corona discharge field for a long time. This leads to the complexity of charger. In addition, high-voltage equipment, complex and expensive to maintain, is used to obtain corona discharges.

Techniques of charging in electrostatic field became the most widely used in installations for electro-aerosol technology. From technical point of view, these methods are easier to implement due to simultaneous aerosol spraying and charging. They require lower charging voltage compared to ion charging, hence they have high energy efficiency.

When electrical aerosol moves in space, it is acted on by gravity and additional electric forces: electrostatic dispersion and mirror image force.

The magnitude and direction of electrostatic dispersion forces depend on the magnitude and the charge of the electro-aerosol drops obtained in generator. With the same charge, electrostatic dispersion forces make electro-aerosol drops repulse each other. This leads to the rapid expansion of electro-aerosol cloud and to uniform filling of treated premises. When electrical aerosol approaches the surfaces to be treated, mirror image forces start to act. These forces increase the rate of electrical aerosol settling and the density of disinfectants deposition on treated surfaces. Thus, it becomes possible to actively manage electro-aerosol treatment of premises [1, 3, 4, 6, 9, 12, 13].

However, the insufficient information on the ways of management of electro-aerosol treatments hinders wide application of this method in agriculture.

## II. Goal of Research

The goal of this research is to obtain a computational model for spreading and settling of electrical aerosol in closed premises which makes it possible to identify patterns of electrophysical processes occurring in electro-aerosol cloud during electro-aerosol treatments.

## III. Materials and Methods

Electro-aerosol treatment of premises can be divided into several stages. These are: formation and initial spreading of electro-aerosol sphere, complete filling of premises with electrical aerosol, and settling of electrical aerosol on the inner surfaces of premises.

Creation and flow of electrical aerosol into premises occurs with the help of electrical aerosol generator. For the model under development, we assume that electrical aerosol spreading is influenced by electrostatic dispersion forces and air pressurizing created by generator, and gravitational forces and electrical aerosol coagulation affect electrical aerosol settling [2, 8, 14].

Thus, electrical aerosol concentration change *dn* in the premises volume during time *dt* during working of generator can be written as

$$\frac{dn}{dt} = \frac{dn_{gen}}{dt} - \left(\frac{dn_e}{dt} + \frac{dn_g}{dt} + \frac{dn_a}{dt} + \frac{dn_c}{dt}\right), \quad (1)$$

where $\frac{dn_{gen}}{dt}$ characterizes the increase in electrical aerosol concentration due to the active work of generator; other equation components determine the decrease in electrical aerosol concentration, respectively, by electrostatic dispersion $\frac{dn_e}{dt}$, gravitational settling $\frac{dn_g}{dt}$, generator air flow $\frac{dn_a}{dt}$ and coagulation $\frac{dn_c}{dt}$.

The change in electrical aerosol concentration when the generator works, we obtain in the following form [4]

$$\frac{dn_{gen}}{dt} = \frac{Q_g}{v_k V} \quad (2)$$

where $Q_g$ – fluid flow, m$^3$/s; $v_k$ – electrical aerosol drop volume, m$^3$; $V$ – volume of premises treated, m$^3$.

The decrease in electrical aerosol concentration because of electrostatic dispersion and gravitational settling can be written in the following form [8]

$$\frac{dn_e}{dt} = \frac{v_e S_2 n}{V}; \quad (3)$$

$$\frac{dn_g}{dt} = \frac{v_g S_1 n}{V}, \quad (4)$$

where $v_e$, $v_g$ – electrical aerosol electrostatic dispersion rate and gravitational settling rate, m/s, respectively; $S_1$ – surface where electro-aerosol particles are settled, m$^2$; $S_2$ – surface where no electro-aerosol particles are settled, m$^2$.

The change in electrical aerosol concentration when exposed to the air flow created by generator will be [4]

$$\frac{dn_a}{dt} = \frac{Q_v n}{V} \quad (5)$$

where $Q_v$ – air flow, m$^3$/s;

Electro-aerosol coagulation is written as [8]

$$\frac{dn_c}{dt} = 8\pi D n^2 r \lambda \quad (6)$$

where $= \frac{kT}{6\pi \eta_v r}$; $\lambda = \frac{q_1 q_2}{2\varepsilon_0 rkT}$;

$D$ – diffusion coefficient, m$^2$/s; $r$ – aerosol particle radius, m; $k$ – Boltzmann constant, J/K; $T$ – temperature, K; $\eta_v$ – air dynamic viscosity, N·s/m$^2$; $q_1$, $q_2$ – electric charges of aerosol drops, C.

Plugging (2)…(6) in (1) we get

$$\frac{dn}{dt} = \frac{Q_g}{v_k V} - \left(\frac{v_e S_2 n}{V} + \frac{v_g S_1 n}{V} + \frac{Q_v n}{V} + 8\pi D n^2 r \lambda\right) \quad (7)$$

The rates of electrical aerosol electrostatic dispersion and gravitational settling $v_e$ и $v_g$ will be determined from the equilibrium condition of the forces acting on the particle and forces of resisting medium during steady-state particle motion

$$Eq = 6\pi \eta_v r v_e; \quad (7)$$

$$mg = 6\pi \eta_v r v_g, \quad (8)$$

where $E$ – electric field strength, V/m; $m$ – aerosol drop mass, kg.

So:

$$v_g = \frac{mg}{6\pi\eta_v r} = \frac{2g\rho_g r^2}{9\eta_v} \quad ; \tag{9}$$

$$v_e = \frac{Eq}{6\pi\eta_v r} , \tag{10}$$

where $\rho_g$ – aerosol particle density, kg/m$^3$.

Electric field strength can be found from Poisson equation. Taking a spherical coordinate system, the solution of Poisson equation is [2]

$$\frac{\partial E}{\partial R} + \frac{2E}{R} = \frac{\rho}{\varepsilon_0} , \tag{11}$$

where $R$ – radius of electro-aerosol sphere, m; $\rho$ – aerosol volume charge, C/m$^3$; $\varepsilon_0$ – electric constant, F/m.

Taking into account that $\rho = qnV$ , we get

$$\frac{\partial E}{\partial R} + \frac{2E}{R} = \frac{qnV}{\varepsilon_0} = \frac{\Sigma q}{4/3\pi R^3} . \tag{12}$$

Integrating equation (12) under boundary conditions $R = 0$, $E = 0$, we get

$$E = \frac{\Sigma q}{4\pi\varepsilon_0 R^2} = \frac{qnV}{4\pi\varepsilon_0 R^2} . \tag{13}$$

Plugging (9, 10) in view of (13) in (6), we get

$$\frac{dn}{dt} = \frac{Q_g}{v_k V} - \left(\frac{1}{24}\frac{q^2 n^2}{\varepsilon_0 \pi \eta_v r} + \frac{mgS_1 n}{6\pi\eta_v r V} + \frac{Q_v n}{V} + 8\pi D n^2 r\lambda\right) \tag{14}$$

We neglected gravitational settling at the stage of creating and expansion of electro-aerosol sphere in order to simplify modeling.

Taking up $V = 4/3\pi R^3$, we get

$$\frac{dn}{dt} = \frac{3Q_g}{4v_k \pi R^3} - \left(\frac{1}{24}\frac{q^2 n^2}{\varepsilon_0 \pi \eta_v r} + \frac{3Q_v n}{4\pi R^3} + 8\pi D n^2 r\lambda\right) \tag{15}$$

When the generator stops working, electrically charged aerosol is spread inside the premises under physical action (electrostatic dispersion and convective air flow).

Taking into account air exchange rate $K_v$ which can be replaced by $Q_v/V$, and substituting in the equation in (14), and taking up $Q_g = 0$, we obtain the equation of concentration change which has the form

$$\frac{dn}{dt} = -\frac{1}{24}\frac{q^2 n^2}{\varepsilon_0 \pi \eta_v r} - \frac{mgS_1 n}{6\pi\eta_v r V} - K_v n - 8\pi D n^2 r\lambda \ . \tag{16}$$

Thus, mathematical models for spreading and settling of electro-aerosol cloud in closed premises were obtained.

## IV. Results and Discussion

Equations (15) and (16) which describe the stages of creation and expansion of electro-aerosol sphere in premises and its settling were solved using numerical techniques.

Modeling results are shown in Figure 1 and Figure 2.

An intensive increase in electrical aerosol concentration occurs immediately after the start of generator work, and within 5 ... 10 s it reaches the maximum value (Fig. 1). The increase in electrical aerosol concentration is mainly influenced by the work of electrical aerosol generator. The highest electrical aerosol concentration was achieved at low values of charging voltage on generator and low productivity. This was due to the low impact of electrostatic dispersion at low flow rates.

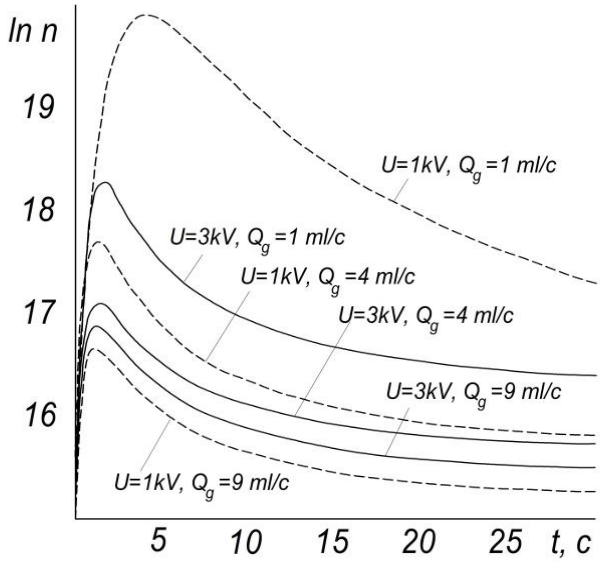


Fig. 1. Dependence of *ln n* on time *t* at different flow rates $Q_g$ and voltages *U* during expanding of electro-aerosol cloud

Subsequently, at spreading of electrical aerosol in space, the number of aerosol particles decreases under the action of electrostatic dispersion and coagulation forces. With low generator performance and low values of aerosol charging voltage, its concentration is set to the highest. Further increase in charging voltage causes an increase in charge on electrical aerosol drops and, accordingly, there are growing influence of electrostatic dispersion forces and electrical aerosol concentration decrease in the volume.

Thus, analysis of Fig. 1 shows that change in charging voltage can be controlled by varying of electrical aerosol concentration over wide range.

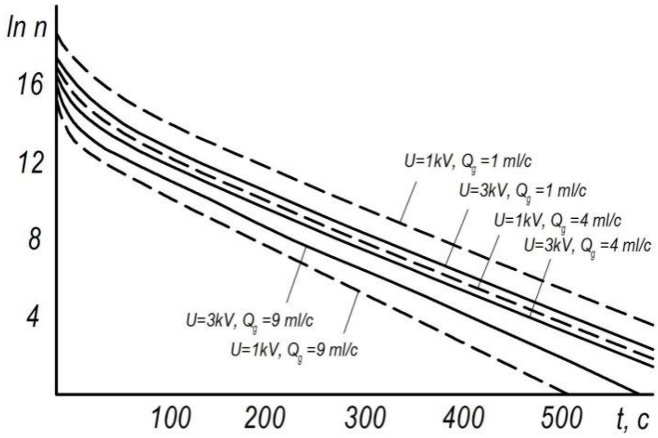


Fig. 2. Dependence of *ln n* on time *t* at different flow rates $Q_g$ and voltages *U* during settling of electro-aerosol cloud

When generator stops working, electrical aerosol concentration decreases almost to zero due to the forces of electrostatic dispersion and gravitational settling (Fig. 2). At the same time, electrical aerosol concentration obtained at high voltages decreases faster than that of low-charged electrical aerosol.

Analysis of equations (15) and (16) shows that significant coagulation appears in highly polydisperse and bipolar aerosols.

## V. CONCLUSIONS AND RECOMMENDATIONS

A simplified mathematical model of spreading and settling of electrical aerosol in large enclosed premises was proposed. This mathematical model includes the technical parameters of electrical aerosol generator: such as generator liquid treatment capacity, air flow and charging voltage. Factors affecting electrical aerosol spreading in premises, such as electrostatic dispersion forces, gravitational settling and coagulation, are also taken into account.

Analysis of this mathematical model shows that the increase in electrical aerosol concentration is mostly affected by the generator performance and aerosol charging voltage. In this case, the value of steady-state concentration can be adjusted over wide range by varying electrical aerosol charging voltage on the generator. This allows flexible control of electro-aerosol treatment of premises.

For the further development of the models of electrical aerosol treatment, the influence of convective flows created by ventilation systems of livestock breeding premises should be taken into account.

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