VALIDATION OF THE METHOD AND PARAMETERS OF AN AIR PURIFICATION SYSTEM FOR REMOVING HARMFUL IMPURITIES USING ELECTROPHYSICAL METHODS
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ОБҐРУНТУВАННЯ СПОСОБУ ТА ПАРАМЕТРІВ СИСТЕМИ ОЧИЩЕННЯ ПОВІТРЯ ВІД ШКІДЛИВИХ ДОМІШОК ІЗ ЗАСТОСУВАННЯМ КОМПЛЕКСУ ЕЛЕКТРОФІЗИЧНИХ ДІЙ

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ABSTRACT
The technological parameters of a device for air purification and disinfection in livestock premises based on the synergistic use of ozonation and ultraviolet (UV) bactericidal radiation are justified. A systematic approach is proposed that ensures high purification efficiency without exceeding permissible ozone concentration limits. An analytical study of the relationships between power input, system performance, bactericidal efficiency, and energy consumption was conducted, and optimal operating modes providing up to 99% air disinfection were identified. The proposed technology is suitable for use in facilities of various purposes, aiming to improve air purification efficiency, reduce energy consumption, and minimize anthropogenic environmental impact.

АНОТАЦІЯ
Обґрунтовано технологічні параметри пристрою для очищення та знезараження повітря у тваринницьких приміщеннях із використанням синергії озонування та ультрафіолетового бактерицидного випромінювання. Запропоновано системний підхід, що забезпечує високу ефективність очищення без перевищення допустимих концентрацій озону. Проведено аналітичне дослідження взаємозв'язків між потужністю, продуктивністю, бактерицидною ефективністю та енерговитратами, визначено оптимальні режими роботи, що забезпечують знезараження повітря до 99%. Запропонована технологія придатна для використання у приміщеннях різного призначення з метою підвищення ефективності очищення повітря, зниження енергоспоживання та мінімізації техногенного впливу на довкілля.

INTRODUCTION
The microclimate of livestock facilities is one of the most influential factors affecting the health, productivity of animals and the economic profitability of the industry as a whole *(Alberta Agriculture and Food, 2008; EU-OSHA, 2019; Specht and Cammaerts, 2000; EPA, 2007).* Modern requirements for microclimate are determined by international standards and scientifically based recommendations in accordance with the type and age group of animals. According to these requirements, the concentration of harmful gases in livestock premises should not exceed the maximum permissible levels for a given animal species: ammonia (NH_3), 10 - 20 mg/m³; carbon dioxide (CO_2), 0.3%; and hydrogen sulfide (H_2S), 5 - 15 mg/m³. In addition, the level of microbial contamination in the working area of the premises should not exceed 50,000 CFU/m³ of air. If the microclimate does not meet optimal zoohygienic parameters, milk yield may decrease by 10 - 20%, animal weight gain by 20 - 30%, and both egg production in poultry and the survival rate of young animals by up to 30%. Moreover, feed and other resources are used inefficiently, and the service life of building structures and installed technological equipment is reduced *(Elaissi et al., 2025; EU-OSHA, 2019; Seinfeld and Pandis, 2016; EPA, 2007; Wathes at al., 2002)*.

Ensuring the concentration of harmful substances within the Microclimates Parameters Control (MPC) is carried out by using active ventilation, as a result of which a significant amount of thermal energy is lost with exhaust ventilation air during the heating period and energy costs increase to maintain the standard air temperature in the room. In the structure of energy costs of livestock and poultry facilities, the costs of maintaining the standard microclimate parameters, according to various estimates, are 35–60%, and harmful physical, chemical and biological impurities with exhaust airflows enter the surrounding environment, increase the technogenic load and worsen the ecological state of the environment.

Within the framework of ensuring regulatory microclimate parameters in livestock premises, physicochemical, biological, and electrotechnological methods, as well as technical means for purifying indoor and ventilation air from pollutants, have been increasingly applied in recent years. As a result, animal housing comfort and working conditions for personnel are improved, while air exchange with the environment and anthropogenic environmental load are reduced. The most effective air purification methods include mechanical and electrostatic filtration, ionization, ozonation, and the use of ultraviolet radiation in the bactericidal spectrum (UVB). A particularly complex scientific and technical challenge is the removal of chemical impurities present in the air, as well as the elimination of pathogenic microflora. While air filtration is effective for removing physical impurities such as dust, animal hair, certain types of microorganisms, and light organic compounds, the removal of chemical pollutants (e.g., ammonia, hydrogen sulfide, and methane) and the inactivation of pathogenic microorganisms require the application of highly efficient electrophysical methods, chemical and biological agents, and absorbents (*Elaissi et al., 2025; Franklin, 2025; Kowalski, 2009; Semenov and Kozhushko, 2013; Semenov and Sakhno, 2021; Steffen, 2008).*

Chemical and biological methods of air purification require consumables, constant supervision and maintenance, therefore, they are used mainly in a periodic mode for preventive purposes. In contrast, electrotechnological methods can be used without constant control, do not require chemical or biological agents and can operate continuously both indoors and at the outlet of ventilation air. For effective purification, it is advisable to use complex approaches using ultraviolet bactericidal radiation and ozonation.

The establishment of relationships and the development of scientific foundations for comprehensive, energy-efficient microclimate control in livestock premises, combined with air purification from harmful impurities, will contribute to improved indoor air quality, better working conditions for personnel, reduced air exchange with the external environment, and lower environmental pollution.

MATERIALS AND METHODS

The justification of the technological parameters of the technical means for air purification is carried out taking into account the requirements for microclimate parameters and modern scientific research and trends in this field. Based on a review of the relevant literature and patent analysis, the following principles and hypotheses are adopted for the development of the air purification system:

– To purify and disinfect air from harmful chemical and biological impurities, a systemic (integrated) approach based on the combined use of the most promising electrophysical factors - ozonation and UVB radiation - is applied *(Elaissi et al., 2025; Franklin, 2025; Kowalski, 2009; Semenov and Kozhushko, 2013; Semenov and Sakhno, 2021; Steffen, 2008)*;

– The air purification system (APS) is designed as a recirculation-type system intended for continuous operation in the presence of people and animals;

– The maximum achievable ozone concentration is generated in the air-treatment chamber using the barrier discharge method, while ensuring compliance with the maximum permissible ozone concentration in the working area;

– The principle of accelerated ozone recombination and oxygen atom release under ultraviolet radiation is applied to enhance the oxidizing effect. In the airflow, ozone is generated first, followed by UV radiation, in order to maximize the residence time of ozone within the active treatment zone (*Elaissi et al., 2025*; *Semenov and Sakhno, 2021; Steffen, 2008).*

The APS operates in a closed mode, as a result of which, after passing through the device, the purified air mixes with the air in the room. In this case, the rational air capacity of the system should be no less than the volume of the room, taking into account the multiplicity of air exchange with the external environment.

Therefore, the functional scheme of the APS will consist of the following main elements (sequentially in the direction of airflow): a fan to ensure air movement, a barrier-type ozone generator, a source of ultraviolet bactericidal (UVB) radiation (Fig. 1).

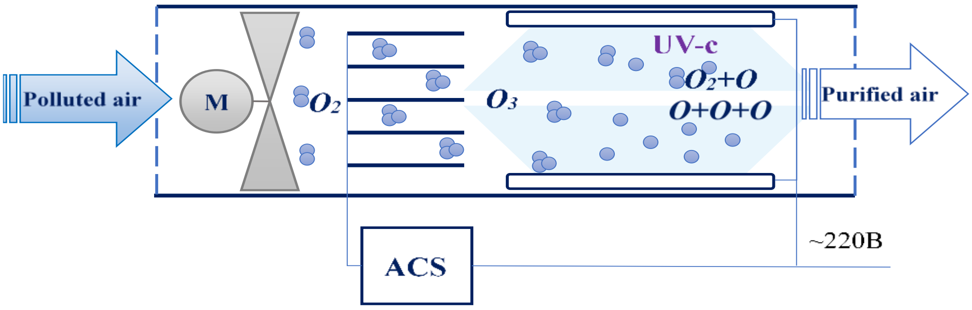

Fig. 1 - Functional diagram of the air purification system (APS) for the removal of harmful chemical and biological impurities

The air purification system (APS) involves the oxidation of harmful impurities by ozone under the influence of ultraviolet radiation (UV) in the B range (280–315 nm). UV radiation performs a dual function — disinfecting and catalytic, activating oxidation processes due to the energy of photons that initiate the decomposition of ozone into active oxygen species. The mechanism of the process includes several sequential stages:

1. Ozone molecules O_3 in the zone of action of UV radiation, photons with energy exceeding the threshold for breaking interatomic bonds are absorbed, resulting in photolysis with the formation of free oxygen atoms. The energy of the photons splits ozone molecules, lowering the energy barrier of oxidative reactions and ensuring catalytic activation of the air purification process *(Bass and Paur, 1985; Brasseur at al., 1999; Meunier, 2006; Seinfeld and Pandis, 2016; Wayne, 2000).*

2. Atomic oxygen O is reactive and within a few picoseconds reacts with impurities or water vapor H_2O with the formation of hydroxyl radicals OH, which are also among the strongest oxidants that effectively destroy organic and inorganic harmful components in the air (*Elaissi et al., 2025; Rice and Netzer, 1984; Meunier, 2006; Semenov and Sakhno, 2021; Steffen, 2008*).

3. Reactive oxygen species O and OH react with volatile organic compounds (VOCs), hydrogen sulfide, ammonia, formaldehyde and other pollutants, converting them into safer products carbon dioxide CO_2 and water H_2O and, at the same time, destroy the membranes of microorganisms, ensuring effective air disinfection (*Elaissi et al., 2025; Rice and Netzer, 1984; Meunier, 2006; Semenov and Sakhno, 2021; Steffen, 2008*).

4. The combined action of ozone and UV radiation creates synergy by enhancing the intensity of oxidative processes. Under the influence of UVB radiation, ozone breaks down to form reactive oxygen species, which accelerates the destruction of chemical and biological impurities even at low ozone concentrations, and UVB radiation additionally destroys the DNA of microorganisms, which increases the effectiveness of disinfection (*Elaissi et al., 2025; Meunier, 2006; Semenov and Sakhno, 2021; Steffen, 2008*).

5. Part of the free (atomic) oxygen that does not participate in the reactions recombines to the oxygen state O_2, as a result of which the ozone concentration at the air outlet is reduced to a safe level, i.e. with high ozone concentrations at the system inlet, a low concentration at the outlet is maintained (*Elaissi et al., 2025; Rice and Netzer, 1984; Meunier, 2006; Semenov and Sakhno, 2021; Steffen, 2008).*

The efficiency of the process is determined by the intensity of UVB radiation, ozone concentration (ozonation efficiency), temperature and air humidity. An increase in the intensity of UVB radiation activates the decomposition of ozone, ensures the formation of reactive oxygen species, and water vapor in the air contributes to the formation of hydroxyl radicals. Temperature affects the rate of reactions and ozone recombination, so its optimization increases the overall efficiency of photooxidation. Therefore, the combination of ozonation with UVB radiation will provide highly effective air purification from chemical and biological impurities due to the synergy of their action and a decrease in the ozone concentration at the system outlet. Such a combined method is promising for effective air disinfection in livestock, industrial, medical and public premises with a controlled microclimate (*Elaissi et al., 2025; Rice and Netzer, 1984; Meunier, 2006; Semenov and Sakhno, 2021; Steffen, 2008*).

In order to ensure regulatory air parameters, in particular qualitative composition, purification from pathogenic microflora and most types of chemical and biological impurities in industrial, agricultural, medical, educational, public and other premises, a functional and technological scheme of a universal air purification system has been developed, which has a block-modular construction principle and is equipped depending on technological requirements and application conditions *(Alhussain at al., 2024; EddaAir, 2023; Airtecnics, 2021; Sankurantripati, 2024; Adamchuk et al., 2021).*

Establishing a relationship between UVB radiation parameters and air performance of an air purification system

Initial data for establishing technical parameters of the APS with a specified geometry of the irradiation chamber and airflow: volume of the irradiation chamber, total bactericidal flux of lamps, radiation utilization factor, airflow rate, average volumetric dose of a specified type of microorganisms, required bactericidal efficiency, reflection coefficient of chamber surfaces.

Criteria for the effectiveness of bactericidal efficiency: irradiation exposure, ozone concentration, UVB radiation intensity, resistance of a certain type of microorganism, standard environmental conditions. The initial parameters make it possible to analytically determine the power of the bactericidal spectrum Φ_{bc} and the ozonation efficiency G_{O3} for a given APS performance in air to ensure optimal air disinfection conditions. The establishment of the bactericidal efficiency of bactericidal UV radiation is based on the irradiation dose D, which is an integral indicator of the product of the irradiation power I and the exposure time t_k *(Block, 2001; Kowalski, 2009; Semenov and Kozhushko, 2013; Martin et al., 2008).*

$$D = I \cdot \tau \tag{1}$$

where: D is the radiation dose, [mJ / cm²];

I— UV radiation intensity, [W/m^2];

τ — irradiation time, [s].

The concept of bactericidal efficiency J_{bc}, %, is formulated as the ratio of destroyed microorganisms to their total number in the environment to which the disinfecting bactericidal action is applied *(Kowalski, 2009):*

$$J_{bc} = \left(1 - \frac{N_{nd}}{N_0}\right) \cdot 100, \tag{2}$$

where: N_{nd} is the the number of non-destroyed microorganisms at the APS outlet;

N_0 – number of microorganisms at the entrance to the APS.

The effective time of airflow irradiation in the air purification system channel τ_c, s, can be determined taking into account the volume of the irradiation chamber and air performance:

$$\tau_c = \frac{3600 \cdot V_c}{V_{ap}}, \tag{3}$$

where: V_c is the volume of effective irradiation (irradiation chamber), [m^3];

V_{ap}– airflow rate, [m^3/h].

The average volumetric bactericidal radiation dose in the system channel H_v, J/m^3, from the condition of bactericidal radiation power, air performance and design features can be formulated as *(Kowalski, 2009; Semenov and Kozhushko, 2013; Martin et al., 2008).*

$$H_v = \frac{N_l \cdot \Phi_{bc} \cdot k_\Phi \cdot k_r \cdot k_d \cdot \tau_c}{V_c}, \tag{4}$$

where N_l is the number of lamps installed in the air-treatment chamber, [pcs];

Φ_{bc}– bactericidal flux of a single radiation source (lamp), [W];

k_Φ– coefficient of utilization of the bactericidal lamp flux. When the lamps are located directly in the airflow, k_Φ = 0.4 – 0.5, when the lamps are installed outside the airflow – k_Φ = 0.7 – 0.8;

k_r– coefficient accounting for multiple reflections of the UVB flux from the chamber walls with a reflection coefficient k_{rb} at the bactericidal wavelength; $k_r = 1/(1 - 0.6 \cdot k_{rb})$

k_d– coefficient representing the decline of bactericidal flux over the lamp service life, with k_d = 0.7–0.8.

The photosensitivity constant of bactericidal radiation is an indicator of the rate of cell deactivation under the influence of UVB radiation, which is defined as a coefficient in the equation of the exponential decrease in the concentration of living cells, usually determined experimentally or the value is taken from the reference literature. For the sanitary indicator microorganism Staphylococcus aureus σ_s = 0.047 m^2/J, σ_v = 0.0179 m^3/J. If the value of the average bactericidal dose of irradiation is available, the photosensitivity constant can be determined analytically for any microorganism.

Accordingly, the dependence (2) can be written as *(Block, 2001; Kowalski, 2009; Semenov and Kozhushko, 2013; Martin et al., 2008).*

$$J_{bc} = 1 - e^{-\sigma_v \cdot H_v} \tag{5}$$

where σ_v is the volume constant of photosensitivity of the microorganism (*S. aureus*) to bactericidal radiation, [m^3/J];

By logarithmic transformation, the surface σ_s, m²/J, and volume σ_v, m³/J, photosensitivity constants of a certain type of microorganism are determined using the following equations:

$$\sigma_s = \frac{-\ln(1-J_{bc})}{H_s}, \quad (6)$$

$$\sigma_v = \frac{-\ln(1-J_{bc})}{H_v} \quad (7)$$

Since the task is to destroy the maximum possible amount of harmful impurities of chemical and biological origin, the analytical dependence (7) for other types of neutralized impurities and substances can be formulated as:

$$H_v = \frac{-\ln(1-J_{bc})}{\sigma_v} \quad (8)$$

and the performance of the air purification system:

$$V_{air} = \frac{3600 \cdot N_l \cdot \Phi_{bc} \cdot k_{\Phi} \cdot k_r \cdot k_d \cdot \sigma_v}{-\ln(1-J_{bc})} \quad (9)$$

Therefore, the bactericidal efficiency, %, depends on J_{bc} (9):

$$J_{bc} = \left(1 - exp\left(\frac{-3600 \cdot N_l \cdot \Phi_{bc} \cdot k_{\Phi} \cdot k_r \cdot k_d \cdot \sigma_v}{V_{air}}\right)\right) 100 \quad (10)$$

If the airflow rate of the APS V_{air}, m³/h, does not change over time, it can be expressed taking into account its design features:

$$V_{air} = const = 3600 \cdot v_{\mathrm{p}} \cdot S_{\mathrm{p}} = \frac{3600 \cdot L_{\mathrm{p}} \cdot S_{\mathrm{p}}}{\tau_c} \quad (11)$$

where S_{p} is the cross-sectional area of the channel, [m²];

v_{p}– air velocity in the channel, [m/s];

L_{p}– length of the irradiation channel, [m].

The basic indicator of the effectiveness of the use of the UVB system is the volumetric bactericidal dose of radiation in the channel H_v, J/m³ (8), *(Block, 2001; Kowalski, 2009; Semenov and Kozhushko, 2013; Martin et al., 2008).*

Taking into account the determined analytical dependencies, the power of bactericidal radiation Φ_{bc}, W, to achieve a given level of bactericidal irradiation J_{bc}, % can be written as:

$$\Phi_{bc} = \frac{-V_{air} \cdot \ln(1-J_{bc})}{3600 \cdot k_{\Phi} \cdot k_r \cdot k_d \cdot \sigma_v} \quad (12)$$

The presented patterns establish the relationship between the parameters of UVB radiation, bactericidal efficiency and performance of air purification systems, and the determined values of air performance and UVB radiation power provide the specified bactericidal efficiency in the room.

Determination of parameters and limitations of the ozonation mode

Since ozone is a toxic substance of the 1st hazard class (permissible concentration in the presence of people and animals is 0.1 mg/m³), and its concentration depends on air parameters: temperature, humidity, air exchange, presence and concentration of harmful impurities, etc., one of the most important scientific and technical tasks is to predict the dynamics of ozone in the working area of the room. Calculation of the power of an ozone generator is a complex task that depends on interrelated parameters that ensure the efficiency, safety and energy saving of air purification. The main factors include: air volume (taking into account air exchange through ventilation), pollution level (which determines the required ozone concentration) and the corresponding ozonation performance (mg/h). The mode and duration of the installation's operation, the expected purification efficiency, the presence of a concentration control and regulation system to maintain a safe level, as well as energy efficiency and compliance with regulatory requirements for maximum permissible concentrations (MPCs) are also taken into account. This approach ensures a rational choice of ozone generator power in accordance with operating conditions, a sufficient level of air disinfection efficiency, and compliance with environmental and sanitary safety requirements.

Mathematical model of ozone photolysis under the influence of UV radiation

If the ozone-air mixture and ultraviolet radiation of the bactericidal spectrum of 254 nm are used in the purification system, ozone photolysis is realized, which creates their synergy and increases the efficiency of air purification. The mathematical model of ozone photolysis is based on the equations of decomposition under the influence of UV radiation in the range of 200–280 nm.

The use of ozone photolysis under the influence of UVB radiation provides:

1. Increasing the efficiency of air disinfection due to the creation of active oxygen species that effectively destroy pathogenic microorganisms and harmful chemical compounds.
2. A decrease in ozone concentration at the system outlet due to the degradation of ozone molecules, which helps to establish the ozone level in the air of the working area at an acceptable level.
3. Air purification in rooms where people and animals are present in industrial, agricultural, livestock, medical, public and other premises with controlled air environment parameters.

The rate of ozone decay characterizes the exponential decrease in light intensity in the environment and is described by the Bouguer–Lambert–Beer law *(Atkins and de Paula, 2010; Brasseur et al., 1999; Seinfeld and Pandis, 2016; Wayne, 2000):*

$$I(x) = I_0 \cdot e^{-\alpha_{O_3} \cdot d_{O_3}} \tag{13}$$

where I_0 is the initial light intensity;

α_{O_3} – ozone absorption coefficient;

d_{O_3} – thickness of the ozone layer.

For stationary input parameters, the ozone degradation rate is determined by the following equation:

$$\frac{dC_{MO_3}}{d\tau} = -k_{UV} \cdot C_{MO_3} \tag{14}$$

where C_{MO_3} is the molar concentration of ozone, [mol/m^3];

k_{UV} – rate constant of the ozone photolysis reaction, [s^{-1}];

τ - process time, [s].

Equation of dynamics of molar ozone concentration taking into account constant ozone generation:

$$\frac{dC_{MO_3}}{d\tau} = G_{O3} - k_{UV} \cdot C_{MO_3} \tag{15}$$

where G_{O3} is the ozone generation efficiency, [mol/m^{3}s].

Provided that the equilibrium state of the equation is reached $\tau \rightarrow \infty$ (15) can be written as:

$$C_{MO_3}^{\text{ст}} = \frac{G_{O3}}{k_{UV}} \tag{16}$$

In this case, the photolysis rate constant k_{UV}, s^{-1}, depends on the intensity (power) of UV radiation, the spectral characteristics of ozone, and the quantum yield of the reaction Φ:

$$k_{UV} = \sigma(\lambda) \cdot \Phi \cdot I \tag{17}$$

where $\sigma(\lambda)$ is the ozone absorption cross section taking into account the radiation wave length, [m^2/molecule];

Φ– quantum yield (probability of photochemical reaction);

I– spectral intensity of UV radiation, [photons/m^2·s].

Model for air purification system duct. It is assumed that the equivalent duct of the air purification system has a length L within which a uniform airflow is established at a constant velocity v_p, m/s. Under these conditions, the time-dependent description of the process can be transformed into a spatial dependence along the flow direction. Therefore, assuming a steady-state flow, the variation in ozone concentration along the duct coordinate is described by the following balance equation:

$$v_p \frac{dC_{MO_3}}{dx} = -k_{UV} C_{MO_3}(x) \tag{18}$$

where: v_p is the average airflow velocity, [m/s];

$C_{MO_3} = C_{MO_3}(x)$– ozone concentration at a distance x from the beginning of the channel.

Integrating from the initial point $x = 0$, i.e. $C_{MO_3}(x) = C_{MO_3}(0)$, to some value of the channel axis coordinate to an arbitrary position x along the duct axis, the following expression is obtained:

$$C_{MO_3}(x) = C_{MO_3}(0) \cdot exp\left(-\frac{k_{UV}}{v_p} x\right) \tag{19}$$

With an effective length L of the irradiation channel, the concentration at the outlet is:

$$C_{MO_3}(L) = C_{MO_3}(0) \cdot exp\left(-\frac{k_{UV}}{v_p} L\right) \tag{20}$$

In this case, the average residence time of air in the channel is given by:

$$\tau_{\text{p}} = \frac{L}{v_p} \tag{21}$$

Taking into account the spatial dependence of the intensity of UV radiation in real conditions, which can vary in the channel due to design features, and also taking into account the assumption that $I = I(x)$, the rate constant becomes a function of the coordinate. Therefore, the mathematical model of ozone photolysis in the channel of the air purification system can be represented by the following system for a constant intensity of UV radiation and for a spatially variable one, respectively:

$$C_{MO_3}(\tau) = C_{MO_3}(0) \cdot e^{-k_{UV}\cdot\tau} \quad , \tag{22}$$

$$C_{O3}(L) = C_{O3}(0)\, e^{-\frac{k_{UV}\cdot L}{v_p}} \tag{23}$$

Using the model, the coefficients describing ozone photolysis for UV radiation of 254 nm were substantiated, which are:

1. Typical ozone absorption cross section value $\sigma(254\text{nm}) \approx 1{,}1 \cdot 10^{-21}$ m²·molecule
2. The quantum yield value $\Phi = 1$ (the probability of ozone decay upon absorption of one photon is close to 100%).
3. The radiation intensity of a low-pressure UVB lamp $I_{energy} = 1.5\frac{mW}{cm^2} = 15\, J/s \cdot m^2$
4. Energy of one photon $E_{photon} \approx 7.83 \times 10^{-19}\, J$
5. Photo Stream $I \approx 1.92 \times 10^{19}\ \ photon/m^2 \cdot s$
6. Ozone photolysis constant $k_{UV} \approx 0.0211\ s^{-1}$
7. Characteristic ozone decay time. $\tau \approx 47\ s$.

These values provide the establishment of the dynamics of the decrease in ozone concentration in the system channel. If more accurate modeling is required, the specifics of the device, the intensity distribution $I(x)$, and the possible deviation of the constant values from the typical ones due to the peculiarities of measurements and experimental conditions should be taken into account. The model makes it possible to establish the dynamics of ozone concentration in the APS channel under the influence of UV radiation, taking into account both the kinetics of photolysis and the spatial distribution of the radiation intensity. Depending on specific initial parameters, such as the geometry of the channel, the airflow rate, the characteristics of the UV radiation source, the optical properties of the medium, etc., it is possible to calculate the efficiency of ozone decomposition. If additional processes occur in the channel (for example, chemical reactions with other components or diffusion), the model can be expanded with additional terms in the corresponding balance equations.

The relationship between energy, design parameters and performance of the ozone generator of the air purification system. Calculation of the volumetric rate of ozone photolysis under the influence of UV radiation 254 nm depends on many factors that must be taken into account for accurate prediction. Determination of parameters and intensity of radiation of the UV range 254 nm. In calculations, it is advisable to use the power of bactericidal radiation of the lamp Φ_{bc}, W. In this case, the bactericidal radiation intensity I_l, W/m², for a point radiation source is given by:

$$I_l = \frac{\Phi_{bc}}{4\cdot\pi\cdot r^2} \tag{24}$$

where: r is the average distance from the lamp to the point where the ozone is located, [m].

The main parameters of the air can be determined analytically using known parameters of the airflow and geometry of the purification system or experimentally. The average air residence time τ_p, s, which is defined as the ratio of the volume of the air-treatment chamber V_c to the system airflow rate V_p, m³/h, is calculated using the following expression:

$$\tau_p = \frac{3600\, V_c}{V_p} \tag{25}$$

The rate constant of the ozone photolysis k_{UV} reaction is determined by the following expression:

$$k_{UV} = I \cdot \sigma \tag{26}$$

Ozone concentration at the outlet of the air purification system irradiation chamber $C_{O_3}(\tau_p)$, mg/m³:

$$C_{O_3}(\tau_p) = C_{O_3}(0) \cdot e^{-k_{UV}\cdot\tau_p} \tag{27}$$

The reduction in ozone concentration at the outlet of the purification system using the equation can be formulated as:

$$\Delta C_{O_3} = C_{O_3}(0) - C_{O_3}(\tau_p) \tag{28}$$

Volumetric rate of ozone photolysis V_{O_3}, mg/s:

$$V_{O_3} = \Delta C_{O_3} \cdot V_{air} \tag{29}$$

Based on the above considerations, the ozonator capacity is first determined under the condition of ensuring a safe ozone concentration at the outlet of the air purification system. For this purpose, Eq. (27) is used, assuming that the outlet ozone concentration satisfies $C_{O_3}(\tau_p)$= 0.1 mg/m³. Under these conditions, the ozone generation rate can be expressed as:

$$G_{O_3} = \frac{C_{O_3}^{(MPC)}}{e^{-k_{UV} \cdot \tau_p}} \cdot V_p \tag{30}$$

Substituting the expressions defining the individual components of Eq. (30), the ozone generation rate takes the form:

$$G_{O_3} = V_{air} \cdot C_{O_3}^{(MPC)} \cdot e^{-\frac{\lambda \cdot \sigma \cdot \Phi_{bc} \cdot \tau_p}{4 \cdot h \cdot c \cdot \pi \cdot r^2}} \tag{31}$$

And taking into account the expression of the bactericidal power of radiation sources Φ_{bc} (12):

$$G_{O_3} = V_{air} \cdot C_{O_3}^{(MPC)} \cdot exp\left(\frac{\lambda \cdot \sigma \cdot V_c \cdot ln(1-J_{bc})}{4 \cdot k_\Phi \cdot k_r \cdot k_d \cdot c \cdot h \cdot \sigma_v \cdot \pi \cdot r^2}\right) = \frac{V_{air} \cdot C_{O_3}^{(MPC)}}{(1-J_{бк})^{\frac{\lambda \cdot \sigma \cdot V_c}{4 \cdot k_\Phi \cdot k_r \cdot k_d \cdot c \cdot h \cdot \sigma_v \cdot \pi \cdot r^2}}} \tag{32}$$

Analytical dependence (32) establishes the relationship between energy and design parameters and the performance of the ozone generator of the air purification system (Fig. 2).

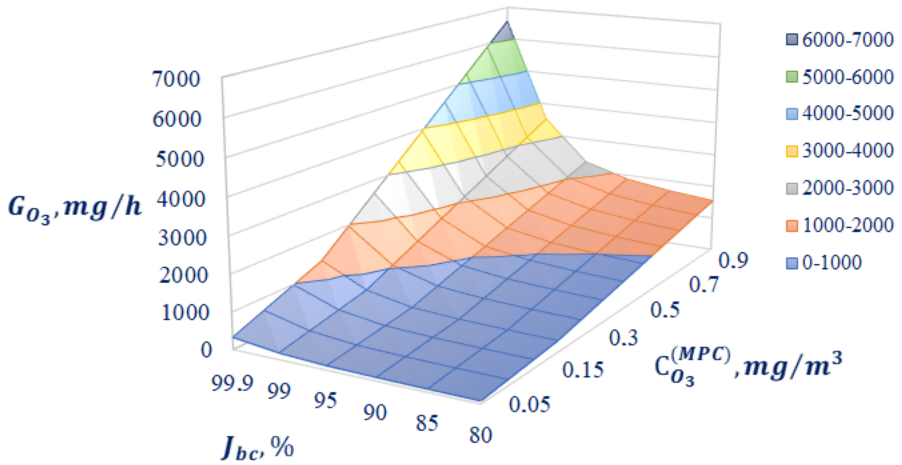

Fig. 2 - Relationship between the design parameters and the performance of the ozone generator in the air purification system

RESULTS

Equation (12) establishes the relationship between bactericidal radiation power and airflow rate for specified values of bactericidal efficiency for a given type of microorganism (Fig. 3a).

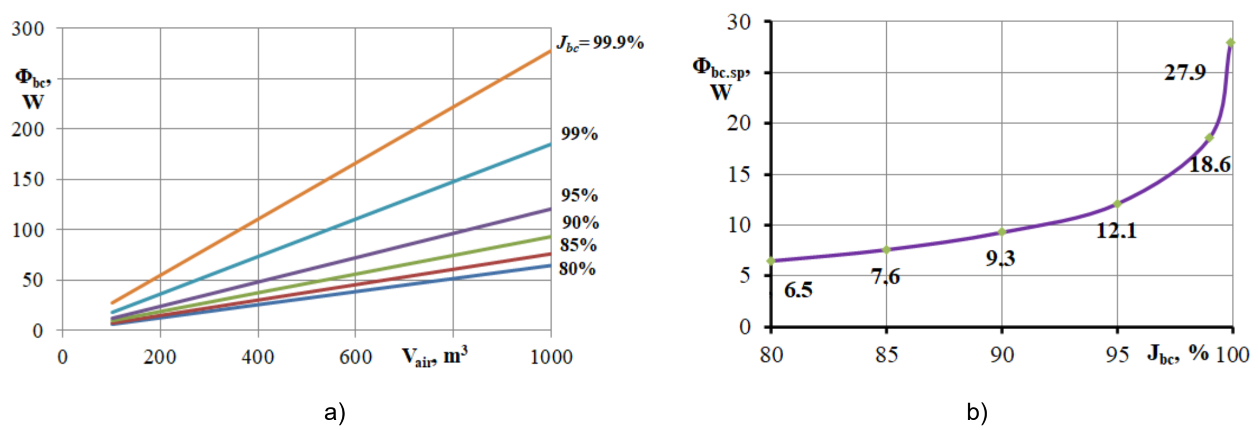

Fig. 3 - Dependence of the bactericidal power of UV radiation sources of the SOP on airflow rate (a) and bactericidal efficiency (b)

When constructing the dependencies, the values of the coefficients were adopted for the developed APS design: $k_{\Phi} = 0.4$, $k_{\text{в}} = 1.2$, $k_{\text{c}} = 0.8$. Each curve can be approximated by a linear equation of the form $\Phi_{bc} = \Phi_{bc.sp} \cdot V_{air}$, where $\Phi_{bc.sp}$ is the specific bactericidal power of the ultraviolet radiation source, W / 100 m^3. In this way, it is possible to determine the specific power of bactericidal radiation to achieve a given level of bactericidal efficiency (Fig. 3, b). To ensure bactericidal efficiency of 80%, the specific power of bactericidal radiation is 6.5 W / 100 m^3, and for 99.9% it is 4.3 times more, 27.9 W / 100 m^3.

From the nature of the relationship shown in Fig. 3b, it can be concluded that achieving a bactericidal efficiency exceeding 95% requires a substantial increase in the power of bactericidal radiation. Therefore, such systems are advisable for use in premises classified as Categories 1 and 2, as well as in agricultural production facilities, subject to a feasibility assessment. Using relationship (12), the dependence between the airflow rate of the APS V_{air} (m^3/h), the bactericidal efficiency J_{bc} (%), and the UVB radiation power Φ_{bc} (W) was established (Fig. 4).

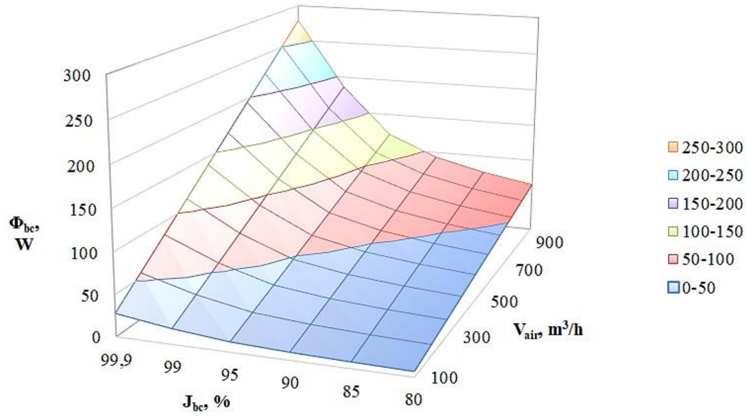

Fig. 4 - Relationship between the airflow rate of the air purification system, bactericidal efficiency, and UVB radiation power

So, to achieve APS with an airflow rate of V_{air} = 1000 m^3/h and bactericidal efficiency of J_{bc} = 90%, a bactericidal radiation power Φ_{bc} = 93 W is required, whereas for J_{bc} = 99% the required power increases to Φ_{bc} = 186 W. For a general assessment of energy consumption associated with air recirculation, the specific electricity consumption W_{p}, W/m^3, can be determined as the ratio of the installed power of the air purification system (fan, UV irradiators and control devices) to the airflow rate, according to the following equation:

$$W_{\text{p}} = \frac{P_{inst}}{V_{air}}, \tag{33}$$

where P_{inst} is the total installed power of the system, [W].

To analyze the dynamics of ozone photolysis, it is assumed that the air purification system operates with an airflow rate of V_{air} = 1 thousand m^3/h (0.28 m^3/s and provides a bactericidal efficiency of J_{bc} = 95% for the sanitary indicator microorganism *Staphylococcus aureus*. The effective dimensions of the irradiation chamber are 0.4 × 0.4 × 1 m (volume V_c = 0.16 m^3), and the average distance from the UV lamp to the ozone is r = 0.1 m. The initial ozone concentration at the inlet of the irradiation chamber (ozonator productivity) is assumed to be $C_{O_3}(0)$ = 1 mg/m^3. Under these conditions, the following parameters are determined:

1. Bactericidal radiation power Φ_{bc}, W, required to achieve a bactericidal efficiency of J_{bc} = 95% (provided $k_{\Phi} = 0.4$, $k_{\text{в}} = 1.2$, $k_{\text{c}} = 0.8$) is calculated using Eq. (12):

$$\Phi_{bc} = \frac{-1000 \cdot ln(1-95)}{3600 \cdot 0{,}4 \cdot 1{,}2 \cdot 0{,}8 \cdot 0{,}0179} \approx 121.3\ W.$$

2. The radiation intensity at the average distance from the lamp, taking into account the geometric dimensions of the irradiation chamber, is I_l, W/m^2 (24):

$$I_l = \frac{121{,}3\ W}{4 \cdot \pi \cdot 0{,}1^2} \approx 963.4\ W/m^2.$$

3. The radiation intensity I, expressed as photon flux density is given by:

$$I = \frac{963.4\ \dfrac{W}{m^2} \times 254\ \times\ 10^{-9}\ m}{6.626\ \times\ 10^{-34} J \cdot \text{c} \times 3\ \times\ 10^8 \dfrac{m}{s}} \approx 1.231 \cdot \frac{10^{21}\text{photons}}{\text{m}^2} \cdot \text{s}$$

4. The average residence time of air in the irradiation zone τ_p is calculated using Eq. (25):

$$\tau_p = \frac{0{,}16\ m^3}{0{,}28\ m^3/s} = 0.576\ s.$$

5. The ozone photolysis reaction rate constant is determined using Eq. (26):

$$k_{UV} = 1.231 \cdot \frac{10^{21}\text{photons}}{\text{m}^2} \cdot \text{s} \cdot 1.15 \times \frac{10^{-21}\ m^2}{molecule} \approx 1.416\ s^{-1}.$$

6. The ozone concentration at the outlet of the purification system $C_{O_3}(\tau_p)$, mg/m³ is calculated using Eq. (27):

$$C_{O_3}(\tau_p) = 10\frac{mg}{m^3} \cdot e^{-1.416\ c^{-1} \cdot 0{,}576\ c} \approx 0.442\frac{mg}{m^3}.$$

7. The reduction in ozone concentration in the irradiation chamber ΔC_{O_3}, mg/m³ due to UV radiation is calculated using Eq. (28):

$$\Delta C_{O_3} = 1\frac{mg}{m^3} - 0.442\frac{mg}{m^3} = 0.558\frac{mg}{m^3}.$$

8. The volumetric rate of ozone photolysis V_{O_3}, mg/s is determined using Eq. (29):

$$V_{O_3} = 0.558\ \frac{mg}{m^3} \cdot 0.28\ \frac{m^3}{s} \approx 0.156\ \frac{mg}{s}.$$

Using the presented methodology, it was established that in a real purification system, the reduction in ozone concentration O_3, mg/m³, significantly depends on the initial concentration, the power of bactericidal radiation, and the time spent in the zone of its action (Fig. 5).

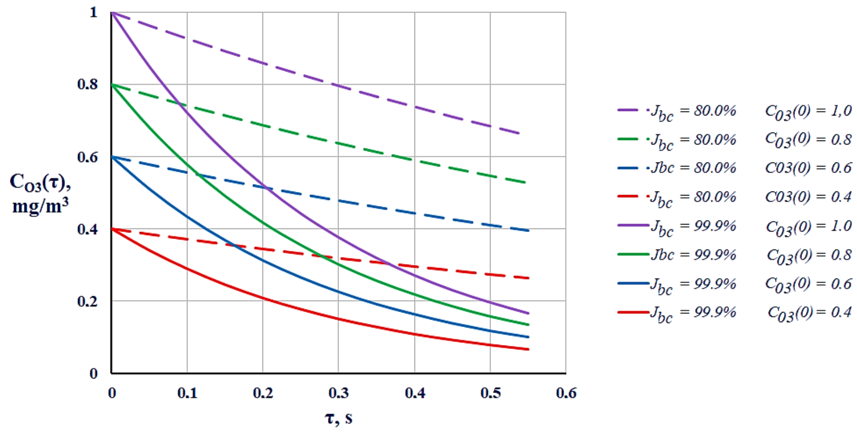

Fig. 5 - Dynamics of ozone photolysis depending on the initial concentration and power of UVB radiation

Thus, with an initial ozone concentration of $C_{O_3}(0)$ = 1.0 mg/m³, an estimated bactericidal efficiency of J_{bc} = 99.9%, the UVB radiation power will be Φ_{bc} = 279 W, and the concentration at the outlet of the APS $C_{O_3}(\tau_p)$ = 0.153 mg/m³ (reduction in ozone concentration ΔC_{O_3} = 0.847 mg/m³, volumetric photolysis rate V_{O_3} = 0.239 mg/s). If J_{bc} = 80.0%, the UVB radiation power will be Φ_{bc} = 65 W, and a $C_{O_3}(\tau_p)$ = 0.645 mg/m³ (ΔC_{O_3} = 0.355 mg/m³, V_{O_3} = 0.099 mg/s).

CONCLUSIONS

As noted earlier, establishing the dynamics of ozone photolysis in air purification systems under the influence of ultraviolet radiation is a complex task, as it requires consideration of numerous factors that significantly affect the reaction rate, including air temperature and humidity, the presence of other substances in the air, as well as the materials and design features of the purification system.

Using the proposed methodology, the following conclusions were drawn:

- To achieve a bactericidal efficiency exceeding 95%, a substantial increase in the power of bactericidal radiation is required. Therefore, such air purification systems are advisable for use in agricultural production facilities, subject to feasibility studies.
- In practical air purification systems, the reduction in ozone concentration strongly depends on the initial ozone concentration, the power of bactericidal radiation, and the residence time of air within the irradiation zone.

To obtain more accurate results, it is necessary to apply more advanced modelling approaches and account for additional influencing factors, such as air temperature, relative humidity, and the presence of other chemical compounds.

For accurate calculation of ozone photolysis and reliable system design, all significant influencing factors must be considered, appropriate analytical methods and equations should be applied, and experimental validation under real operating conditions should be conducted. In addition, to ensure compliance with the specified air purification performance and permissible ozone concentration levels, the implementation of real-time automatic monitoring and control systems is required.

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