Microwave gas discharge source of biologically active UV radiation and ozone as efficient means for sanitation of the indoor air

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Abstract. A new system of UV sanitization of the air environment in the premises of OVOD-1a, based on high-efficiency microwave gas discharge lamps developed in GPI RAS, is described. The first experiments demonstrating the air purification capabilities of UV equipment were carried out. It is shown that in the laboratory premises used for the stay of livestock breeding in agriculture, the energy price of almost complete purification of the air from viral and fungal components is about \( \eta \approx 10^{-2} \text{kW} \cdot \text{h/m}^3 \). Bacterial sanitation of laboratory space is carried out with an energy cost of \( \eta \approx 3 \cdot 10^{-2} \text{kW} \cdot \text{h/m}^3 \). The fundamental physical processes underlying microwave UV lamps, which are the main component of OVOD-1a sanitation system, are discussed.

1 Introduction

A new type of UV sanitation devices was developed. It is based on the fundamental studies of the phenomena that occur in microwave discharges in air and in different gas mixtures [1–3]. As a result, electrodeless lamps were developed and studied. In such lamps a low-pressure discharge is initiated by microwave radiation [4–7]. One of the methods of the discharge initiation is the transformation of the microwave radiation into a surface wave on the plasma–dielectric boundary [8–9]. These UV lamps have a high efficiency of transforming the electric energy into the energy of UV radiation [3, 6, 10–13]. The new powerful UV generators [3, 4, 13, 14], based on these UV lamps, have a potentially wide range of applications. It is known that the high-intensive UV radiation induces oxidative

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stress in living organisms, which suppresses the life activity of biological objects [15]. Under the oxidative stress, the redox homeostasis is violated [16] and the nucleic acids [17], proteins [18] and some other molecules are damaged. At unacceptably high levels of damage of the biological molecules, the cells stop functioning and die. Such an UV-radiation device may be used to sanitize surfaces in human and veterinary medicine, food industry, etc.

The use of industrial technologies in modern livestock production causes high levels of indoor air and surfaces contamination with pathogenic bacteria and viruses. As a result, risks of infecting the livestock with, e.g., grippusavium, swine influenza, Pasteurellosis, etc. [19–21] highly increase. Different means of livestock and poultry farms sanitation based on chemical/physical methods and their combinations are developed [22–24].

The objective of this work is to estimate the sanitation efficiency of the OVOD-1a device with respect to the microorganisms in the indoor air. In this paper the possibility of sanitizing the air in different rooms, including livestock farms, by means of OVOD-1a is discussed. The results of the device testing in the vivarium of the Federal Research Center of Virology and Microbiology (FRCVM) and a GPI RAS laboratory are presented and discussed.

2 Methods

2.1 Equipment

The development of a new UV-source OVOD-1a was based, at first, on the studies of microwave energy absorption in the plasma resonance region [12, 25]. This effect has led to the production of a high-energy electron component. Another important effect is the formation of a microwave discharge in a system with a truncated electrode. Figure 1 shows the scheme of the OVOD-1a device.

![Fig. 1. Scheme of the OVOD-1a device: 1 – UV lamps, 2 – magnetron, 3 – power supply, 4 – quartz glass, 5 – fan.](image)

The device consists of several (4–6) innovative electrodeless gas-filled (Ar + Hg) quartz UV lamps, a microwave radiation generator (magnetron) and an original microwave energy
input system into the lamps. The lamps generate biologically active UV radiation in two modes. In the first mode, UV radiation with a wavelength $\lambda \approx 254$ nm is generated with efficiency $\approx 120$ lm/W. In the other mode, UV radiation with a wavelength $\lambda \approx 185$ nm is generated (in addition to radiation with $\lambda \approx 254$ nm). This UV-radiation produced ozone in the air flow, which simultaneously produces ozone. Four cylindrical 70-cm-long 2.5-cm-diameter UV lamps are used in the construction of the OVOD-1a device. The microwave radiation is produced by a magnetron similar to the one used in the household microwave ovens. The radiation is generated in a pulse-periodic mode with microwave pulse duration $\tau_i \approx 8$ ms and the delay between the pulses $\tau_{pi} \approx 12$ ms (the frequency is 50 Hz). The pulse power is $P_i \leq 2$ kW and the average pulse power is $P_{av} \leq 325$ W. The microwave radiation wavelength is $\lambda = 12.5$ cm.

The placement of the microwave generator and UV lamps in a metal case provides reliable protection of the operating personnel from the UV radiation and microwaves. A fan is used for pumping (at rate $S_a \approx 210–270$ m$^3$/h) of the contaminated air through the working zone (chamber) for sanitation. There, in the first mode, it is irradiated only by UV radiation of the lamps with $\lambda \approx 254$ nm. In the other mode, it is irradiated by UV radiation with a wavelength $\lambda \approx 185$ nm and produced ozone in the air flow. Figure 2 shows the scheme of the working area of the OVOD-1a device. Figure 3 shows a photograph of the device.

Fig. 2. Scheme of the working area of the OVOD-1a device: top view and side cross section. 1 – antenna (central electrode of the coaxial waveguide), 2 – microwave generator (magnetron), 3 – chamber through which the contaminated air is pumped for sanitation, 4 – quartz tube, 5 – UV lamps, 6 – port for air pumping, 7 – ventilator that provides air cooling of the UV lamps, 8 – rectangular waveguide.
Fig. 3. Photograph of the OVOD-1a device.

The main features of the OVOD-1a device are the following: (i) high efficiency of generating UV-radiation; (ii) small dimensions and weight, allowing one to move it easily from one room (building) to another; (iii) reliable protection of the operating personnel from UV and microwave radiation, (iv) longevity of the device (determined primarily by the longevity of the UV lamps); (v) two operating modes: sanitizing the air by either only the UV radiation at a wavelength of $\lambda \approx 254$ nm, or simultaneously irradiate the biological objects by the direct UV radiation (at wavelengths $\lambda \approx 254$ and 180 nm) and ozone, generated in the process of UV radiation at wavelengths $\lambda \approx 180$ nm interaction with flowing air. In the second case the sanitation efficiency significantly increases (in some cases).

2.2 Experimental method

The OVOD-1a device can be used, in particular, to sanitize the indoor air in the livestock sector of the agricultural industry. The maximum time $\tau(h)$, necessary for sanitation of the air in a room, can be estimated as the following:

$$\tau \approx \frac{V}{S}$$

(1)

where $V$ is the building volume in m$^3$ and $S$ is the speed of air pumping through the device in m$^3$/h. To estimate the efficiency of the sanitizing effect of the OVOD-1a device, we calculated the energy efficiency $\eta$ of the bactericidal, anti-spore and fungicidal effect of the device,

$$\eta \approx \frac{P_{\text{air}} \tau}{V}$$

(2)

is the time of operation of the system during which the initial microbiological contamination of the air decreases by one order of magnitude.
The air sanitation with the OVOD-1a was carried out in a vivarium with a volume \( V = 130 \text{ m}^3 \), in which animals used for experiments and control of biological substances were kept before the very start of the experiment.

The microbial content in the air was determined by the method of sedimentation on solid mediums such as the tryptone soya yeast extract agar (TSYEA) and the Sabouraud agar (SA) to reveal the bacterial and fungal microflora, respectively. The total microbial count (TMC, the total number of microorganisms in 1 cm\(^3\) of air) was calculated by the Omelyansky formula \([24, 25]\). The air samples at each exposition time were taken in five (critical) areas at distances of 1, 2, 2.3, 3.5, and 5 m from the OVOD-1a device, respectively. For determining the microbial content in the air before the experiment, two Petri dishes with nutrient agar mediums (TSYEA and DA) were placed in each sampling point for the duration of one hour. Afterward, OVOD-1a device work for 30, 60, and 120 minute periods. At the end of these periods, the device was switched off and new Petri dishes with TSYEA and DA were placed in the sampling points for one hour. At the end of the exposition time, the Petri dishes were closed and placed in a thermostat. The inseminations were incubated at a temperature (37±1 °C) to reveal the bacterial contaminants and at a temperature (28±1) °C to reveal the fungal contaminants. The results are shown in the Table 1.

### Table 1. The sanitizing effect of the OVOD-1a device on the naturally contaminated air of vivarium areas.

| Operation time, min | Bacterial content in air, CFU/m\(^3\) | Mold fungi content in air, CFU/m\(^3\) | TMC, CFU/m\(^3\) |
|---------------------|------------------------------------------|-----------------------------------------|-------------------|
| 0 (control)         | 70.4                                     | 88.9                                    | 159.3             |
| 30                  | 157.4                                    | 283.3                                   | 440.7             |
| 60                  | 37.0                                     | 33.3                                    | 70.3              |
| 120                 | 53.7                                     | 57.4                                    | 111.1             |

\(^a\)CFU stands for colony-forming units.

The obtained results demonstrated, that the OVOD-1a device achieves its highest bactericidal and fungicidal efficiency at an exposition time of 60 min. At this exposition time, the bacterial load of the air decreased by 4.25 times and the fungal load decreased by 8.5 times. On average, the TMC (bacteria and mold fungi count per 1 m\(^3\) of air) decreased by 6.2 times after a 2-hour-long exposition. After the 2-hour-long exposition, the microbial landscape of the air mainly consisted of the Penicillium ssp. fungi and Bacillus ssp. bacilli. The energy expenditure \( \eta \) of this sanitizing effect of the UV source on the air environment in the vivarium estimated from (2) is \( \eta = 10^{-2} \text{kW·h/m}^3 \).

An increase of 2.7 times in the microbial content of the air after a 30-minute-long exposition compared to the control value, in our opinion, can be the result of the operation of the fan of the OVOD-1a device, which lifts the dust and microbial particles from the floor and suspends them in the air.

Another room, where the air was sanitized from microbiological components with help of the OVOD-1a, was a GPI RAS laboratory. The experiment was carried out in a closed nonventilated area with a volume \( V ≈ 192 \text{ m}^3 \) (length \( b = 8 \text{ m} \), width \( a = 7.5 \text{ m} \), height \( h = 3.20 \text{ m} \)) by the method described above. In this experiment the fan productivity was 400 m\(^3\)/h. The sanitary condition of the air was estimated by the Koch method and the Omelyansky formula \([26]\) using the TMC determined after a 30-minute-long exposition. It is shown, that after this exposition time the microbial count decreases by more than one order of magnitude, what corresponds to the energy expenditure of sanitation \( \eta_2 ≈ 3\cdot10^{-2} \text{kW·h/m}^3 \).
It is necessary to note that the presence of bulky objects and equipment in the room leads to decreasing air sanitation rate.

3 Results

The electrodeless UV lamps, in which a low-pressure discharge is initiated by microwave radiation, were developed and studied in GPI RAS. The lamps have a high efficiency of transforming the electric energy into the UV radiation energy. Based on the UV lamps, a new promising type of efficient generators of the biologically active UV radiation was developed. One such powerful microwave gas-discharge UV radiation source, the OVOD-1a device, was used to study the efficiency of the sanitation of the air in the vivarium area of FRCVM and a GPI RAS laboratory. The experimental results demonstrated the efficiency of the developed UV equipment against air contaminants. It is shown that the energy expenditure of a near-total air sanitation from microorganisms of bacterial and fungal etiology in the vivarium room at FRCVM is \( \eta_1 \approx 10^{-2} \text{KW} \cdot \text{h} / \text{m}^3 \). The energy expenditure of the air sanitation in the laboratory room at GPI RAS from the bacterial microflora is \( \eta_2 \approx 3 \cdot 10^{-2} \text{KW} \cdot \text{h} / \text{m}^3 \).

4 Conclusions

A new generator of the biologically active UV radiation, based on electrodeless microwave pumped lamp, was developed. It is shown that this UV device can be successfully used to sanitize indoor air, in particular, in the livestock sector of the agricultural industry. The device specificity is its high efficiency against sporous microorganisms such as the bacillar flora and mold fungi. This is the matter of great importance for solving many practical tasks. We assume, that this specificity of the OVOD-1a device is due to the simultaneous action of UV radiation and influence of UV-generated ozone on the air, flowing through the chamber zone of the device.

The OVOD-1a device can also be used to sanitize the air in medicinal rooms, food industry buildings, transport, etc. One of the important areas of its application is livestock and poultry farms. The new scientific results obtained as a result of our studies are in good agreement with the data of various scientific studies that have been obtained by other scientists [27-38].

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