Microwave gas-discharge device OVOD-1a sanitizing indoor air

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Abstract. A new UV scanning system OVOD-1a for the indoor air environment, based on high-performance microwave gas-discharge lamps developed at GPI RAS, is described. The first experiments demonstrating the air-cleaning capabilities of UV equipment were carried out. It is shown that in laboratory rooms used for the stay of livestock bred in agriculture, the energy cost of almost complete purification of the air environment from viral and fungal components is of the order of $10^{-2}$ kW·h/m³. Bacterial sanitation of the laboratory premises of the research physical Institute is carried out with an energy cost of $\approx 3 \times 10^{-3}$ kW·h/m³. The fundamental physical processes underlying microwave UV lamps, which are the main component of the OVOD-1a sanitation system, are discussed.

Keywords: microwave gas-discharge, OVOD-1a, sanitizing, indoor air

1. Introduction

Research at the General Physics Institute of the Russian Academy of Sciences (GPI RAS) on fundamental problems of microwave discharge radiation in air and in various gas mixtures [1-5] formed the basis for the development of a new type of UV lamps that have high efficiency of converting electrical energy into biologically active ultraviolet energy [6-11]. The microwave ultraviolet lamps were the main circuit-forming element of high-power UV radiation generators in various versions of the OVOD-1a device [4,6,10,11], which have a potentially wide range of applications. These include medicine, food industry, transport, and others. In this paper, we consider ways to solve two urgent problems: sanitation of the air environment in the premises of livestock farms, as well as in medical and preventive institutions. The main goal is to study the possibilities of putting modern sterilization equipment into operation for air sanitation. The demand for this type of activity is related, in particular, to the fact that nosocomial infections have become one of the problems of the health system. In the United States, for example, up to 100,000 people a year die from hospital-acquired infections. It is also of great interest to sanitize the premises of livestock farms and poultry farms, aimed at preventing epidemics such as "bird flu" (Grippus avium), "swine flu" (Swine influenza) and other diseases that have a detrimental effect on modern...
agriculture. This article presents a description of the OVOD-1a system created at GPI RAS, designed for the rehabilitation of both air and solid surfaces and fluid flows. The results of testing the device in the working rooms of VNIIVVM RAS, as well as in the laboratory rooms of GPI RAS as a UV radiation generator that provides an effective sanitizing effect on the air environment containing bacterial, spore and fungal contamination are presented and discussed.

**Figure 1.** Schematic image of the OVOD-1a system.  
1-fan; 2-quartz tube; 3-UV lamp; 4-magnetron; 5-magnetron power supply.

**Figure 2.** Scheme of the reaction part OVOD-1a.  
1-antenna (central coax electrode); 2-magnetron; 3 – room air pumping chamber; 4-quartz tube; 5-UV lamps; 6-air supply pipe; 7-fan cooling UV lamps; 8-rectangular waveguide.

2. Powerful gas-discharge microwave generator of biologically active radiation "OVOD-1a".  
Principle of operation, features and performance characteristics

Ultraviolet microwave gas-discharge radiation source that sanitizes the air environment of premises was developed by GPI RAS in such a way as to meet the following requirements:

- High power of the generated bioactive ultra-violet, which provides the possibility of rapid suppression of bacterial, spore and fungal components of the treated air environment;
- Mobility, small size and weight of the device, allowing to easily move it within one room or from one room of the building to another;
- Reliable protection of personnel, patients of medical institutions, biological objects of livestock and poultry farms from exposure to ultraviolet radiation and microwaves at a level exceeding the permissible values;
- Long-term service life of the device elements (especially UV lamps);
- Ability to adjust the UV radiation spectrum with the introduction of a regulated ozone exposure channel, in addition to direct UV exposure to the microbiological component; The OVOD-1a installation that meets these requirements is shown schematically in Fig. 1. The device is based on a microwave gas-discharge source of ultraviolet radiation, which includes a system of gas-filled (Ar + Hg) quartz lamps, a microwave radiation generator, and an original system for inserting microwaves into lamps [12]. The
advantages and innovative solutions include, first of all, the design of lamps that have a high efficiency of generation by microwave discharges of biologically active UV radiation ($\lambda_f \approx 254$ nm) ($\approx 120$ lumen/Watt). The coefficient of transformation of the energy of microwave gas-discharge plasma into the energy of biologically active UV radiation reaches 60% in UV lamps used in OVOD-1a. The lamps do not contain any metal inclusions (electrodes, leads to them, etc.) that reduce the level of radiation of bactericidal UV and significantly reduce the time of preservation of efficiency. Lamp life exceeds 10,000 hours.

The generation of microwave radiation is carried out by a magnetron and its power system, similar to those used in modern household microwave ovens. Generation is performed in the pulse-periodic mode, where the duration of the microwave pulse is $\tau_i \approx 8$ ms, and the time interval between pulses is $\tau_{bi} \approx 12$ ms. The pulse power of $P_i \approx 2$ kW, the average power of the $P_{av} \approx 1$ kW. The wavelength of microwave radiation $\lambda = 12.5$ cm. The original scheme for powering a UV gas-discharge lamp system with powerful microwave radiation provides a low linear energy release and a low (50°C) gas temperature necessary for effective UV generation. The obvious advantage of the energy input system is also that it provides the necessary compactness of the device. Placing the microwave generator and UV lamps in a closed metal box provides reliable protection of service personnel and biological objects from UV and microwave radiation.

The scheme of the reaction part OVOD-1a is shown in Fig. 2. The figure shows a device with four lamps (top view and side view), 1-an antenna (central coax electrode), 2-a microwave generator (magnetron), 3-a chamber through which the purified room air is pumped (at a pumping rate of $S_0 \approx 210 – 270$ m$^3$/h), 4-a quartz tube, 5 – UV lamps, 6 – an air supply pipe, 7 – a fan that provides air cooling of the lamps, 8 – a rectangular waveguide.

A photo of the ready-to-use device is shown in Fig. 3. When installing the current OVOD-1a in a closed scanned room, the wiring time of all the air contained in it through the reaction zone with direct interaction with the UV emitted by the lamps and with the ozone accumulated in the gas stream is:

$$\tau_s \approx V_r / S_0 \text{ (h)},$$

where $V_r$ is the volume of the room in m$^3$, and $S_0$ is the speed of pumping air through the OVOD-1a in m$^3$/h. $S$ is the minimum time required for processing the scanned room.

3. Experiments demonstrating the possibilities of air sanitation of industrial premises by the OVOD-1a system

Demonstration of the sanitizing capabilities of the OVOD-1a system was carried out at two sites: - in the laboratory room (Lab 1) in the building located in the city of Pokrov (VNIIVVM RAS) and - in the laboratory room (Lab 2) of GPI RAS. To characterize the effectiveness of the disinfection effect on the air environment of the premises, the value of the energy price $\eta$ of the bactericidal, anti-spore and anti-fungal action of the device was determined:

$$\eta \approx P_{av} \tau_s / V_r \text{ (kWh / m}^3\text{)}$$

where $\tau_s$ is the duration of the sanitizing system under test, which reduces the initial content of sources of microbiological contamination of the air by an order of magnitude.

3.1. Sanitation of the air environment in the room (Lab 1)

The Lab 1 room was a working room with a volume of $V_r = 93$ m$^3$, where animals used in microbiological experiments were kept in cages before processing. Microbial contamination of air was determined by sedimentation on solid nutrient media of yeast trypton-soy agar (DTSA) and Saburo agar (SA) to identify bacterial and fungal microflora, respectively. Air sampling for each exposure was performed at three points at distances of 1.75, 3.0, and 3.4 m from the UV installation. Previously, to determine the microbial background in the room, air samples were taken for 1 hour (initial samples). 4 Petri dishes with agarized nutrient media (DTSA and CA) were installed at each selection point. The next step in the experiment was to turn on the UV installation OVOD-1a. One Petri dish was removed from each selection point every 30 minutes and placed in a thermostat with temperature of 28 and 37°C, respectively. The selection duration was 30, 60, 90, and 120 minutes after the unit was turned off. At the end of the exposure time, OVOD-1a was turned off and Petri dishes with DTSA and CA were installed at the same selection points for a period of 1 hour. After exposure, the cups were placed in thermostats. The
results of microflora detection are presented in Table 1. These tables indicate that after two hours of operation, the unit reduces the bacterial load of air (CFU bacteria/m³) by 6.7 times, and the fungal load (CFU mold/m³) by 7.3 times. The energy cost of achieving this kind of sanitizing effect of the UV source on the specific air environment of the laboratory room of VNIIVVM RAS, estimated from the expression (2), turns out to be: \( \eta_{L1} \leq 10^{-2} \text{kWh/m}^3 \) (3) The microbial landscape of the air after a 2-hour exposure is mostly represented by spore-forming fungi from the genus *Penicillium* and bacilli from the genus *Baillus*.

### Table 1

| Exposition          | Average number of CFUS | TMN, CFU/cup | CFU, mold/m³ | CFU, bacteria/m³ | TMN, CFU/m³ |
|---------------------|------------------------|--------------|--------------|------------------|-------------|
| Before disinfection | 6.7                    | 13.0         | 19.7         | 172.0            | 89.0        | 261.0       |
| After disinfection  | 1.0                    | 1.7          | 2.7          | 22.5             | 13.2        | 36.0        |

DTCA – yeast trypton-soy brath; CA – agar Saburo

3.2. Sanitation of the air environment in the room (Lab 2)

The second object that was sanitized by the OVOD-1a system was a laboratory room in the Plasma Physics Department of the GPI RAS. Loaded with equipment and containing two operating experimental facilities, the laboratory was visited by a limited number of employees. Cleaning the atmosphere in the laboratory from microbiological components is complicated by the presence of a large number of hard-to-reach dead air zones between the elements of the equipment filling the room.

The experiment was conducted in a closed, unventilated room with a length of \( b = 8 \text{ m} \), a width of \( 7.5 \text{ m} \), and a height of \( h = 3.20 \text{ m} \) (\( V_r = 192 \text{ m}^3 \)). The open Petri dishes numbered from 1 to 5 are placed at different heights for 1 hour. After an hour, the cups are closed and the UV installation OVOD-1a located in the room with a fan with a capacity of 398 m³/hour is turned on for 35 minutes. After this time, open Petri dishes with numbers from 6 to 10 are placed at different heights and left for another 1 hour, after which the cups are closed. Assessment of the sanitary and bacterial state of the air by the total microbial number (TMN) by the Koch method was carried out using the Omeliansky formula. The Koch sedimentation method is that Petri dishes with the medium are left open for a certain time (5-10 minutes for the total contamination and at least 40 minutes for the cocci microflora), then they are closed and kept in a thermostat for 24 hours and 24 hours at room temperature. The number of grown colonies corresponds to the degree of air pollution: according to an approximate calculation, as many microbes settle on an area of 100 cm within 5 minutes as they are contained in 10 liters of air. The number of microorganisms determined by the Koch method is often expressed in conditional so-called colony-forming units (CFU).

During the experiment, the value of the microbial number (the content of the total number of microorganisms in 1 cm³ of air) was determined in a closed room "Lab 2" during half-hour operation of the UV generator OVOD-1a located in it. It is shown that during the action of the sanitizing device, the microbial number decreases by more than an order of magnitude. This corresponds to the energy cost of rehabilitation:

\[ \eta_{L2} \approx 3 \times 10^{-3} \text{ kW h/m}^3 \] (4)

Note once again that the described device OVOD-1a is a multifunctional device that can be easily converted into a variant of UV cleaning of the flow of consumed water or into a variant of disinfection of the surfaces of objects located inside the room (with the removal of UV lamps, as shown in the photo Fig. 4).
4. Conclusion

Over the past decade, the GPI RAS a cycle of fundamental studies of gas-discharge plasma, which allowed to create device OVOD-1a, which is a generator of biologically active UV radiation and is suitable, in particular, for readjustment of the air environment in premises of the livestock sector of agriculture, and also in premises of medical institutions urban and rural health. Two fundamental physical phenomena discovered and investigated at GPI RAS formed the basis of a new gas-discharge UV source. These are the processes of absorption of microwave energy in the "plasma resonance" region [9,13], which cause the appearance of a high-energy electronic component, and the processes of forming a microwave discharge in a coaxial system with a "truncated" electrode [12]. Methods for implementing processes that form both one and the other phenomena in highly sub-threshold microwave electric fields have made it possible to create a compact, highly efficient generator of biologically active UV. The first experiments demonstrating the sanitation capabilities of the new UV equipment were carried out. It is shown that in laboratory rooms used for the stay of livestock bred in agriculture, the energy cost of almost complete purification of the air environment from viral and fungal components is about $\leq 10^{-2}$ kW·h/m³. Bacterial sanitation of the laboratory premises of the research physical Institute (GPI RAS) is carried out with an energy cost of $3 \times 10^{-3}$ kW·h/m³. It should be noted that the obtained values $3 \times 10^{-3}$ kW·h/m³ are overstated due to imperfect isolation of the air environment of the tested premises from the extra-room space. However, even in such far from optimal conditions, OVOD-1a demonstrates significant advantages over similar standard systems. Evaluating the new UV system as an air sanitizing device, it should be noted that when working in VNIIVM premises, the high efficiency of exposure to spore and fungal components of air impurities in comparison with the effectiveness of the bactericidal one. It can be assumed that the advantage of the OVOD system, which is so important for the problems of modern animal husbandry, is connected with the possibility of simultaneous exposure of both UV radiation and controllably generated ozone to the treated air environment.
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