Characteristics of the experimental setup for ozone fumigation of biological objects

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This paper describes the setup of the ozonogenerator designed at the Institute of Atmospheric Optics SB RAS. The ozonogenerator was used for creating excess O_3 concentrations when investigating ozone effect on plants. The control over the O_3 content in the ozone-air flow is made by the spectrophotometric method.

It is well known that the increased concentration of O_3 in the air or water is capable to disinfect them. On the other hand, ozone is toxic and has a bad effect on the human respiration organs as well as the plant productivity.[1] The maximum permissible ozone content in the air of rooms, where people work, is 0.1 mg/m^{3} (Ref. 2).

At the Institute of Atmospheric Optics a series of ozonogenerators of different capacity have been developed, which can be used both for sanitary cleaning of houses and for disinfection of drinking water and industrial wastewater. The schematic diagram of the ozonogenerator includes a thyristor voltage converter and a discharge chamber based on ceramics. The ozone generation is carried out in the air flow directed by a fan to a discharge chamber. The device design is highly reliable. The expenditure of energy to producing ozone is about 10 W×h/g. For comparison, the expenditure of energy in industrial ozonogenerators is 16–40 W×h/g[2].

If high ozone concentrations are required, the module switching-on of the devices is used that makes it possible to create stations with high ozone capacity. The true ozone content in the ozone-air flow at the ozonogenerator output can be determined by the spectrophotometric method.

Fig. 1. Experimental setup: lamp VSB–1 *1*; UV and interference filters *2*; mechanical modulator *3*; polyethylene chamber *4*; ozonogenerator *5*; photomultiplier *6*; selective voltmeter *7*; A/D converter *8*; computer *9*.

In our experiments on the investigation of the effect of the increased O_3 concentrations on plants the setup (Fig. 1), incorporating the "Ozone–IAO" generator, was designed. The generator was mounted in the polyethylene chamber of the volume $V = 0.25$ m[3] (the fumigation chamber) and was switched on for the required time of ozone acting on the plants.

It is well known that ozone spontaneously dissociates, and the rate of ozone decay depends on the humidity, temperature, air pollution,[3,6] the material of chamber walls, and on the type of the objects of research, therefore we studied preliminary the change of ozone concentration with time in the empty fumigation chamber.

The ozone content was tested continuously in the chamber using the spectrophotometric method. As a radiation source, a high-frequency electrodeless lamp of VSB-type, filled with a natural mixture of mercury isotopes, was used. Two light filters, UFS–5 and an interference filter, were used to isolate from the lamp radiation spectrum the resonance radiation line at $\lambda = 254$ nm corresponding to the maximum of the ozone absorption band. The radiation modulated at a frequency of 900 Hz, passed through the fumigation polyethylene chamber filled with the ozone and air mixture and then fell on a solar-blind photomultiplier. A signal from the photomultiplier was recorded by a selective microvoltmeter tuned to the modulator frequency and then a rectified signal was fed to the computer A/D converter.

A similar procedure was used to assess the ozonogenerator capacity. In this case, when determining the O_3 concentration, the source and the receiver were located across the flow of the ozone and air mixture received from the generator. To determine the flow rate, a special chamber was filled with the ozone–air mixture (the chamber volume was previously determined by a gas counter GSB–400) and the time of chamber filling was registered. The productive capacity
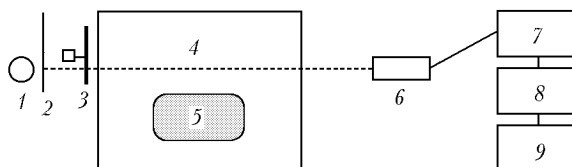
of the model of "Ozone−IAO" ozonogenerator, used in the experiment, after estimating the flow rate and the ozone concentration in the flow at room temperature of 18°C and the relative humidity of 60% was assessed as 2 g/h.

The ozone concentration n (cm^{-3}) was determined by the Bouguer law from the measured transmission T of the radiation at $\lambda = 254$ nm by ozone−air mixture

$$T = I/I_0, \quad I = I_0 \exp(-\sigma nl), \quad n = -(\ln T)/\sigma l,$$

where I_0 is the incident radiation intensity, I is the radiation intensity passed through the absorbing layer, σ is the ozone absorption cross section at $\lambda = 254$ nm. According to the data from Ref. 4, $\sigma = 1.14 \cdot 10^{-17}$ cm^2. The absorption cross section of different gases at this wavelength can be neglected [the absorption cross sections of oxygen, benzene, sulfur dioxide at this wavelength are equal to: $2 \cdot 10^{-24}$; $1.3 \cdot 10^{-18}$ and $3.4 \cdot 10^{-19}$ cm^2 (Ref. 5)].

The results of the ozone concentration variation in the empty chamber, after turning on the ozonogenerator during 60 s, are given in Figs. 2 and 3. To take into account the possible additional decay of O$_3$ on the plants placed in the chamber, we measured the ozone concentration in the chamber in which the cedar branches were placed, that occupied about 1/5 part of the chamber volume. The ozonogenerator was turned on for the periods of 10, 30 and 60 s, and then the chamber was ventilated.
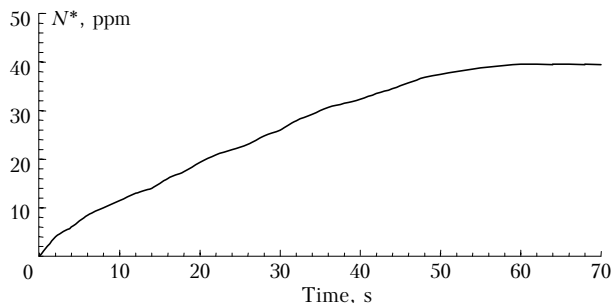

Fig. 2. Variation of ozone concentration in the chamber of 0.25 m^3 volume after switching on the ozonogenerator.
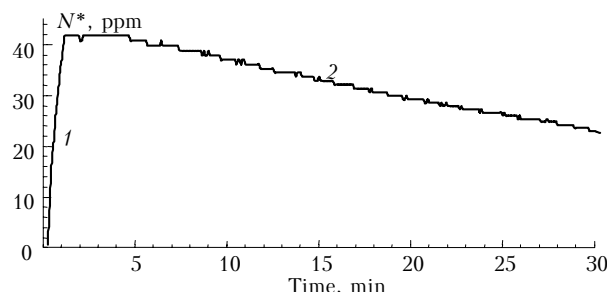

Fig. 3. Filling with ozone of the polyethylene chamber (*1*) and spontaneous decay of ozone after switching off the generator (*2*). The chamber volume is 0.25 m^3. The time of the generator operation is 1 min.

Table 1 shows the measurements of ozone concentration in the empty chamber and the chamber

with cedar branches depending on the duration t of the operation of the ozonogenerator as the mean of three realizations (the confidence coefficient is 0.8). The table shows the values of the dose of O$_3$ effect on the plants and the mean concentration. These characteristics are determined as[1]:

– the maximum concentration $N^*_{max} = \max\{n(t)\}$, $t \in [t_1, t_2]$;

– the dose $D = \int n(t)\,dt$, where $n(t)$ is the reacting ozone concentration over a period of reaction $[t_1, t_2]$;

– the mean concentration $n = D/(t_2 - t_1)$.

Table 1

t, s	Maximum O$_3$ concentration in the empty chamber, N^*_{max}, ppm	Maximum O$_3$ concentration in the chamber with cedar branches, N^*_{max}, ppm	Dose D, ppm · s	Mean O$_3$ concentration in the chamber with cedar branches, N^*, ppm
10	13.3 ± 1.1	13 ± 1.6	88	8.8
30	25.8 ± 2.1	27.4 ± 2.4	464	15.5
60	38.0 ± 2	41.6 ± 1.5	1044	17.4

As is seen from the table, the ozone content in the fumigation chamber with branches and free of branches remains constant within the limits of measurement errors, i.e., during the fumigation the supplementary O$_3$ decay on the pine branches was not observed.

Figure 4 shows the dynamics of O$_3$ decay for some time in the closed polyethylene chambers of different volumes. It is evident that the increase of the chamber volume reduces the spontaneous decay of ozone on the walls. Therefore, when fumigating biological objects by ozone, the polyethylene chambers of larger size are preferable.
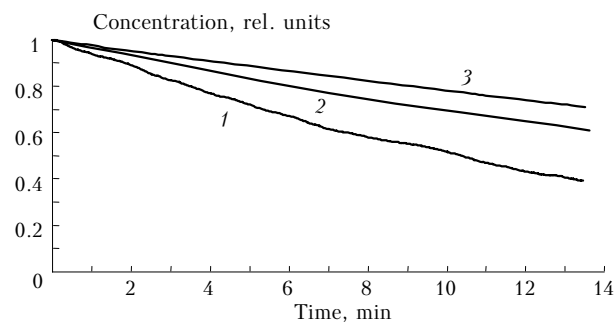

Fig. 4. Spontaneous decay of ozone in closed fumigation chambers of different volume: 0.01 m^3 (*1*); 0.25 m^3 (*2*); and 1 m^3 (*3*).

For reference, Table 2 shows the values of the coefficients, by which the concentration n (or the density ρ) should be multiplied to obtain the values of the pressure, density, and relative ozone concentration.

Table 2

Value	Pressure p, hPa	Density ρ, g/m³	Relative units (relative to air)					
			Mass concentration		Molar concentration		Volume concentration	
			$r = \rho_i/\rho_s$ (Ref. 7)	r, ppm	$r^* = N_i/N_s$	r^*, ppm	$N^* = p/P_s$	$N*$, ppm
n, cm⁻³	$\dfrac{P_0 T}{T_0 N}$	$10^6\, m_0\mu$	$\dfrac{\mu_i}{\mu_{air}} \dfrac{P_0 T_{air}}{P_{air} T_0 N}$	$10^6 \dfrac{\mu_i}{\mu_{air}} \dfrac{P_0 T_{air}}{P_{air} T_0 N}$	$\dfrac{P_0 T_{air}}{P_{air} T_0 N}$	$10^6 \dfrac{P_0 T_{air}}{P_{air} T_0 N}$	$\dfrac{P_0 T_{air}}{P_{air} T_0 N}$	$10^6 \dfrac{P_0 T_{air}}{P_{air} T_0 N}$
for O₃	$1.38{\cdot}10^{-19}\, T$	$7.97{\cdot}10^{-17}$	$2.28{\cdot}10^{-19} \dfrac{T_{air}}{P_{air}}$	$2.28{\cdot}10^{-13} \dfrac{T_{air}}{P_{air}}$	$1.38{\cdot}10^{-19} \dfrac{T_{air}}{P_{air}}$	$1.38{\cdot}10^{-13} \dfrac{T_{air}}{P_{air}}$	$1.38{\cdot}10^{-19} \dfrac{T_{air}}{P_{air}}$	$1.38{\cdot}10^{-13} \dfrac{T_{air}}{P_{air}}$
ρ, g/m³	$\dfrac{1}{\mu_i} \dfrac{P_0 V_0 T}{T_0}$	–	$\dfrac{1}{\mu_{air}} \dfrac{P_0 V_0 T_{air}}{T_0 P_{air}}$	$10^6 \dfrac{1}{\mu_{air}} \dfrac{P_0 V_0 T_{air}}{T_0 P_{air}}$	$\dfrac{1}{\mu_i} \dfrac{P_0 V_0 T_{air}}{T_0 P_{air}}$	$10^6 \dfrac{1}{\mu_i} \dfrac{P_0 V_0 T_{air}}{T_0 P_{air}}$	$\dfrac{\mu_{air}}{\mu_i} \dfrac{1}{\rho_{air}}$	$10^6 \dfrac{\mu_{air}}{\mu_i} \dfrac{1}{\rho_{air}}$
for O₃	$1.73{\cdot}10^{-3}\, T$	–	$2.87{\cdot}10^{-3} \dfrac{T_{air}}{P_{air}}$	$2.87{\cdot}10^3 \dfrac{T_{air}}{P_{air}}$	$1.73{\cdot}10^{-3} \dfrac{T_{air}}{P_{air}}$	$1.73{\cdot}10^3 \dfrac{T_{air}}{P_{air}}$	$0.47{\cdot}10^{-3}$	$0.47{\cdot}10^{-3}$

N o t e . $N = 2.687{\cdot}10^{19}$, in cm⁻³, is the Loschmidt number; μ is the relative molecular mass (dimensionless value); $\mu_{O_3} = 48$, $\mu_{air} = 29$; μ_i is the molecular weight, g/mol; m_0 is the atomic unit of mass, $1.66{\cdot}10^{-24}$ g; $P_0 = 1013.25$ hPa; $T_0 = 273$ K; $V_0 = 22.4{\cdot}10^{-3}$ m⁻³/mol; $R = P_0 V_0/T_0 = 83.14{\cdot}10^{-3}$ hPa·m⁻³/(mol · K); $PV = (M_i/\mu_i)\, RT$; $M_i/\mu_i = N_i$ is the number of moles, M_i is gas mass; $\rho_{air} = 1.29$ kg/m³ $= 1.29{\cdot}10^3$ g/m³.

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