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Photocatalytic Recyclers for Purification and Disinfection of Indoor Air in Medical Institutions

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TIOKRAFT experimental photocatalytic recyclers are suggested for cleaning and disinfection of indoor air in various facilities, including hospitals. It is demonstrated that these recyclers can be effectively used to purify air from volatile organic pollutants, aerosols, and fungal and bacterial microflora. The photocatalytic recyclers reduce microbiological contamination of the air in hospital facilities by an order of magnitude. Thus, the recyclers can be considered as promising agents of protection against nosocomial infections.

Introduction

Hospital infections are a significant cause of the secondary diseases and complications arising in the process of medical treatment. According to Expert Working Group on Research of Nosocomial Infections data reported at the XVI Russian Conference on Contemporary Problems and Prospects of Antimicrobial Therapy, in 2013 the rate of hospital infections in the medical institutions of Russia was 7.61%. Airborne infections spread via respiratory droplets or dust are especially common. Therefore, methods for reducing the microbial air contamination in hospitals are especially important for elimination of secondary hospital-acquired infections.

The routine approach to air decontamination used in medical practice is based on the use of quartz bactericidal lamps emitting in the short-wavelength UV range (254 nm). However, the efficacy of the quartz treatment is insufficiently high. In addition, quartz lamps produce ozone, which is detrimental to human health.

Systems for air filtration based on HEPA filters are finding increasing application for air decontamination. The disadvantages of these systems are high cost of removable filter cartridges and low efficiency of entrapment of aerosols with particle size less than 300 nm. Filters and ventilation channels of such systems also tend to accumulate microflora. This can lead to spontaneous release of contaminants as the system is switched on and off.

In recent years, the photocatalytic method has been intensely developed in many countries. This method may become a solution to the problem of deep disinfection of air with complete inactivation of all species of microorganisms. The essence of the method is the production of active oxygen-containing particles on the surface of the photocatalyst (titanium dioxide semiconductor) induced by exposure to radiation within the UVA range (315-400 nm). Such photoactive particles are able to oxidize all organic substances coming into contact with the photocatalyst. In contrast to mechanical filters, the photocatalytic filters provide not only entrapment of molecular and aerosol organic pollutants (including pathogens), but also their decomposition into harmless components (carbon dioxide and water).

It was reported in [1] that the concentration of pathogenic bacterial and fungal cultures effectively decreased in hospital facilities as a result of the use of the Airocide photocatalytic reactor. The main element of the reactor is a reaction chamber formed by a multitude of glass rings covered with titanium dioxide. Inside the chamber is a 60-W UVB lamp (mean wavelength, 254 nm). High-energy radiation within this range is accompanied by

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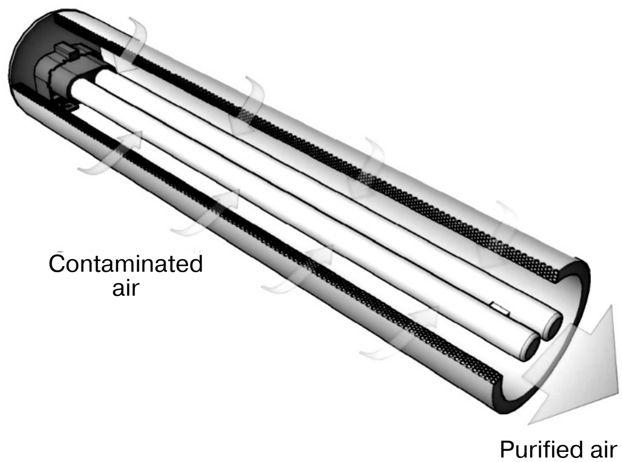

Fig. 1. Photocatalytic element.

ozone production. It was demonstrated that installing the Airocide system in a typical surgery department led to an approximately 60% decrease in the concentration of airborne microbes.

The literature contains insufficient information on the use of photocatalytic recyclers working in the UVA range for air disinfection in medical facilities, particularly in surgery and intensive care departments.

Research Goal

The goal of this work was to study the efficiency of photocatalytic devices working in the safe UVA range for cleaning and disinfection of indoor air in hospital facilities.

Materials and Methods

TIOKRAFT recyclers. The research was carried out using experimental photocatalytic recyclers of two types: TIOKRAFT VL-40 and TIOKRAFT VR-400A [2, 3]. The main specific feature of the TIOKRAFT recyclers is the use of photocatalytic elements based on porous glass elements of tube- or plate-like shape developed by the authors' team [4]. The elements are chemically stable against photocatalytic oxidation. The recyclers provide reliable fixation of photocatalyst powder. They are easily flushed and have sufficient structural strength.

A diagram illustrating the construction of a single photocatalytic element is shown in Fig. 1.

Air is flushed through a porous glass plate coated with catalytically active titanium dioxide. Inside the element there is an UV lamp illuminating the surface of the photocatalyst. Because the medium is strongly oxidizing as a result of photocatalysis, microorganisms are inactivated and molecular organic pollutants are oxidized.

The TIOKRAFT devices tested in this work differ from each other by the organization of air flow inside the device, efficiency of air purification, and presence or absence of additional purification units. The TIOKRAFT VL-40 convection photocatalytic recycler is characterized by an air purification productivity of up to 40 m^3/h. The power of the UV lamps emitted in the photocatalytically active spectral range is 36 W. A steady air flow is produced by heat-generated convection in a vertical channel containing the catalytic elements. The channel is formed by 32 plates with catalyst. The size of each plate is 400 × 60 × 6 mm. The dimensions of the device (W × D × H) are 290 × 96 × 1860 mm.

The other device used in the study, TIOKRAFT VR-400A, is an apparatus for complex purification of large volumes of air. In addition to the photocatalytic purification unit, this apparatus contains a dust filter and a unit for aerosol electrodeposition. Preliminary mechanical filtration and use of an aerosol electrodeposition unit coupled with the photocatalytic element provide a high degree of air purification and long-term operation without replacement of photocatalytic elements. Air flow through the apparatus is produced by a fan with an adjustable feed rate of 120-400 m^3/h. The photocatalytic unit contains four tube-shaped elements (external diameter, 86 mm; length, 400 mm). The power of the catalytically active UV radiation lamp is 36 W. The dimensions of the device (W × D × H) are 520 × 300 × 1060 mm.

Methods. The experiments in removing volatile organic pollutants (VOPs) from air were implemented using the TIOKRAFT VL-40 device. A model pollutant (acetone, formaldehyde) with a given initial concentration was placed in a sealed box of 10 m^3. Then the device was switched on and the time dynamics of the pollutant concentration was monitored. At the same time, the dynamics of the concentration of carbon dioxide (a product of oxidation of organic compounds) in the air was measured.

The experiments in aerosol removal were carried out using the TIOKRAFT VR-400A device. Tobacco smoke was used as a model aerosol. The concentration of aerosol particles in the air flow at the inlet and outlet of the device was monitored using an SMPS 3936 spectrometer (TSI Inc.). A curve of the aerosol particle distribution over size was plotted.

The experiments in air purification from microbiological pollutants were carried out using both the TIOKRAFT VL-40 and TIOKRAFT VR-400A devices. The tests were performed in actual laboratory and surgical facilities: the surgery of the vivarium of the Institute of Problems of Chemical Physics, Russian Academy of Sciences; the Laboratory of Mycology of the All-Russia Center of Plant Quarantine; and the cardiac intensive care unit of Moscow Municipal Clinical Hospital No. 70. The time dependence of the number of colony-forming units (CFUs) in the air was measured as a function of the duration of operation of the recycler. Samples were collected by flushing air through a FLORA-100 impactor, in which Petri dishes with a sterile incubation medium were installed. Upon collection of the samples, the Petri dishes were placed into an incubator and kept at 37°C for 48 h. The sample collection sites were uniformly distributed over the area of the facilities. Samples were taken at a height of 1 m above the floor. After calculation of the number of colonies, the XYZ projection was mapped and the spatial interpolation mesh was plotted using Shepard's method [5, 6].

Results

Air purification from VOPs. The results of the air purification from model organic pollutants in the 10-m^3 test box using the TIOKRAFT VL-40 device are presented in Table 1. The initial acetone concentration in the air was 8 times higher than the maximum concentration limit (MCL) for the working zone; the concentration of formaldehyde was 3.4 times higher than the MCL. As acetone was removed, the content of carbon dioxide in air was measured. In

TABLE 1. Results of Air Purification from Model Pollutants

Operation time, min	Acetone oxidation		Formaldehyde oxidation
	Concentration, mg/m^3		Concentration, mg/m^3
	C_3H_6O	CO_2	CH_2O
0	1657	0	1.71
10	1075	1099	1.38
20	840	1670	1.18
30	630	2325	0.89
40	322	3035	0.56
50	98	3572	0.26
60	3	3730	0.19
70	2	3735	0.14
80	0	3739	0.11
90	–	–	0.09
100	–	–	0.06
110	–	–	0.04

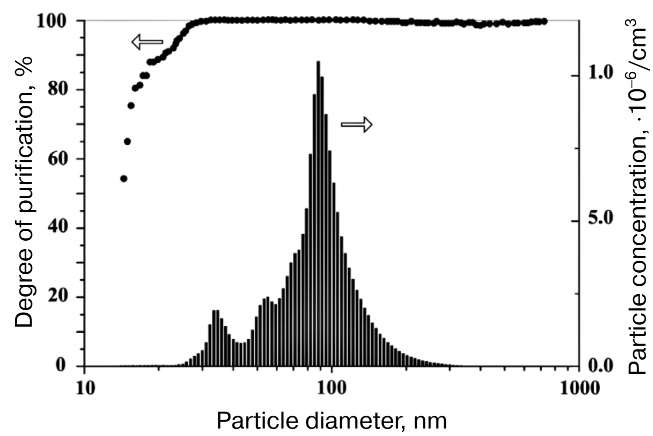

Fig. 2. Efficacy of air purification from tobacco smoke particles.

experiments with formaldehyde, such measurements were not carried out because the sensitivity of the device was insufficient to measure low CO_2 concentrations.

It follows from Table 1 that the concentrations of acetone and formaldehyde vapors in air 50 min after the start of the purification procedure fell below the MCL. The decrease in the organic (acetone) concentration was accompanied by an increase in the CO_2 concentration. This result is consistent with the oxidative mechanism of photocatalytic purification.

Air purification from aerosol. The size distribution of the particles of tobacco smoke used as a model contaminant in the tests of the TIOKRAFT VR-400A device is shown in Fig. 2. It can be seen that the aerosol mainly contains particles ~90 nm in size. The top curve in the figure shows the degree of purification of the air at the device outlet.

The experiments demonstrated that the particles larger than 20 nm in size were completely removed from the air after a single passage through the device. Smaller particles were removed less efficiently. However, the fraction of such particles in tobacco smoke is small; therefore, it is safe to suggest that the TIOKRAFT VR-400A device provides almost 100% efficacy of air purification from aerosols such as tobacco smoke.

Air purification from microbiological contamination. The TIOKRAFT VL-40 convection photocatalytic recycler was tested at the Laboratory of Molecular Biology, Institute of Problems of Chemical Physics, Russian Academy of Sciences. The area of the laboratory room used in the tests was 35 m^2. The duration of the test was 42 h. During this time, the concentration of microorganisms (mainly *E. coli* and staphylococcus) in the air was reduced by more than 10 times with respect to the initial concentra-

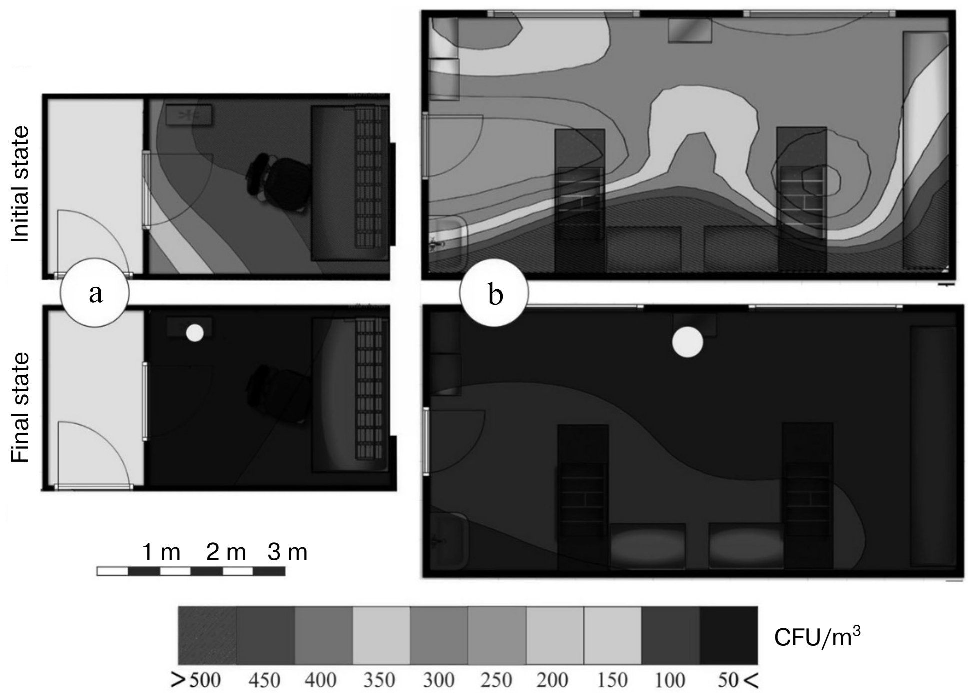

Fig. 3. Comparative maps of microflora distribution in the air of the (a) Laboratory of Mycology and (b) vivarium surgery before and after purification with the photocatalytic recycler.

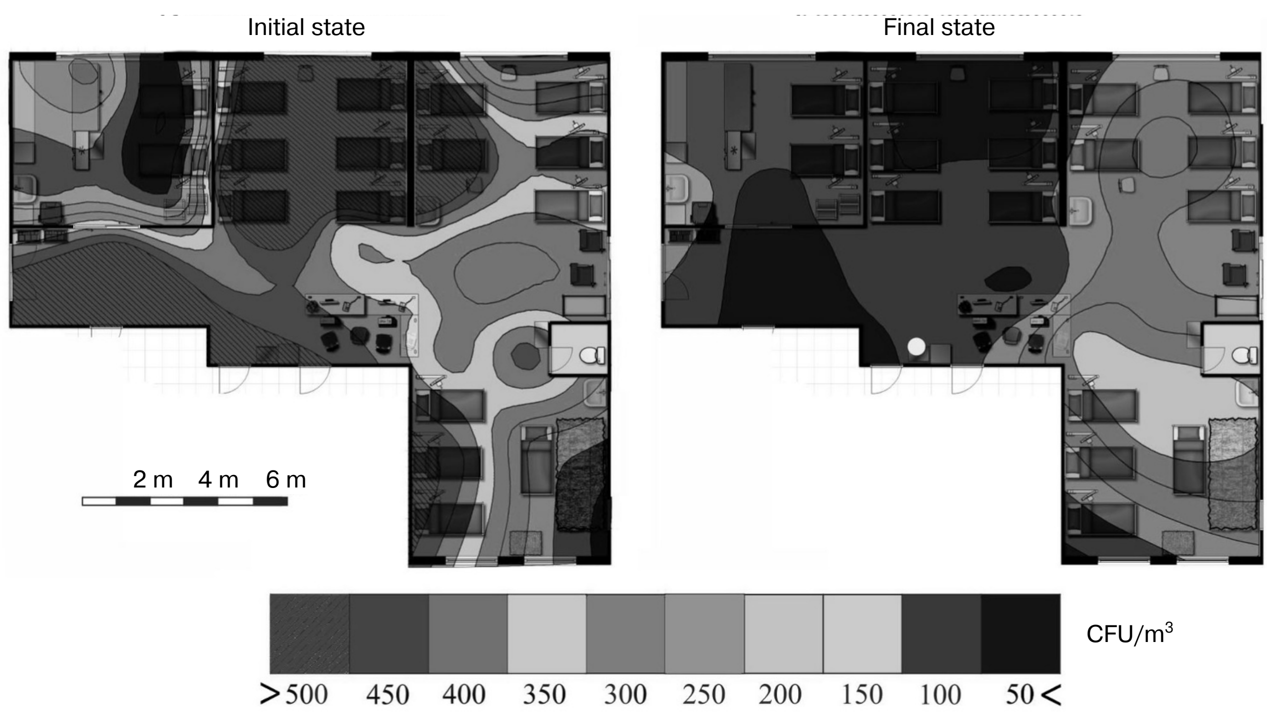

Fig. 4. Results of the air purification in the intensive care unit.

tion of 375 CFU/m^3. The device also demonstrated high efficacy of air purification from fungi during the tests performed at the Laboratory of Mycology, All-Russia Center of Plant Quarantine. The tests were performed in a 6-m^2 room. A map of the fungi concentration in the air at the beginning of the test and after 48 h of continuous operation of the device is shown in Fig 3a. The CFU concentration in the air was reduced by more than 10 times.

Similar results were obtained in the tests of the TIOKRAFT VR-400A recycler in rooms with larger areas. For instance, in the surgery (area 50 m^2) of the vivarium of the Institute of Problems of Chemical Physics, Russian Academy of Sciences, the level of microbiological contamination of the air decreased by approximately 10 times even within the first 24 h of operation of the device (Fig. 3b).

Positive results of air purification in facilities with high requirements for air sterility were obtained at Moscow Municipal Clinical Hospital No. 70. The results of the air purification in the intensive care unit (160 m^2) using the TIOKRAFT VR-400A recycler are illustrated in Fig. 4. These results were obtained after 5 days of operation at the rate of 120 m^3/h [7]. The position of the device in the room is indicated in Fig. 4 as a white dot.

The tests reported above demonstrate that the concentration of microorganisms in air decreases by an order of magnitude or more as a result of photocatalytic purification.

Conclusion

The tests of the new TIOKRAFT devices for air purification and disinfection based on an original photocatalytic element made of fused porous glass demonstrated the high efficacy of air purification from molecular organic contaminants, aerosol nanoparticles, and typical bacteria and fungi. The devices use an ozone-free UV lamp and nanocrystalline titanium dioxide as the photocatalyst.

Using such air recyclers, the degree of bacterial contamination of the air can be reduced by an order of magnitude. Thus, they can be recommended for air disinfection in medical facilities. The main purpose of the disinfection is to reduce the incidence of hospital-acquired infections.

We are grateful to all who participated in the microbiological tests of the air purifiers in facilities with different functional purposes.

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