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# DEVELOPMENT OF EQUIPMENT FOR AIR DECONTAMINATION IN THE VENTILATION AND AIR CONDITIONING SYSTEMS OF PUBLIC BUILDINGS WITH THE USE OF THE PHOTOCATALYSIS AND PLASMOCHEMISTRY METHODS

***Introduction.*** *Seasonal waves of SARS outbreaks, including COVID-19, necessitate the development of measures to create health-safe conditions in crowded places.*

***Problem Statement.*** *The existing supply and exhaust systems of the centralized heating, ventilation and air conditioning (HVAC) do not protect against infection, moreover, they serve as a source for the accumulation and spread of pathogenic microorganisms. Finding effective ways to clean the air in places of mass gathering of people as a component of anti-epidemic measures is an urgent task.*

***Purpose.*** *The purpose of this research is to develop and create equipment for cleaning and disinfecting air from airborne pathogenic microflora in the HVAC systems, which can be installed in the centralized ventilation systems of buildings without their reconstruction and modifications in technological parameters.*

***Material and Methods.*** *A complex of physical and chemical methods, which includes analytical and experimental techniques with the use of the theory of electrogas dynamics of dispersed systems and the raster scanning microscopy methods, and the methods for comparing the same quality indicators of specimens and initial samples have been used.*

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***Results.*** *To study the efficiency of both the individual plasma-chemical and photocatalytic modules, as well as the equipment as a whole under the operating conditions that simulate those of the centralized ventilation system, an experimental stand has been created. The optimal technological parameters of the processes for raising the efficiency of air disinfection and purification in the HVAC systems by the plasma photocatalysis methods have been determined. Technical solutions for increasing the energy efficiency of the experimental stand for the complex air purification and disinfection from a wide class of air pollutants in the supply and exhaust ventilation systems of buildings have been proposed.ent, as well as to determine the required level of innovation factor by maximizing the hidden innovation capacity.*

***Conclusions.*** *Air disinfection by the method of combined plasma-photocatalytic effect on the air flow with a system for catalytic-thermal decomposition of excess ozone ensures effectively removing pollutants and allows reducing the microbiological contamination of the air to a safe level.*

*Keywords: air dispersion, air purification, plasma chemistry, photocatalysis, pathogenic microflora, and efficiency.*

With the spread of the SARS-CoV-2 coronavirus that has put the world in permanent pandemic conditions, the problem of protecting people's health, which is especially relevant in megacities with a significant density population of population becomes very important and needs to be urgently addressed. According to the World Health Organization and the Public Health Center of Ukraine, the new coronavirus spreads by contact, airborne, dustborne, and through fomites. The available data on SARS-CoV-2 have indicated that it has a high aerosol and surface stability. So, the coronavirus can survive for several hours in the form of an aerosol and up to three days on plastic and steel surfaces. The half-life of the viral particles depends on the temperature and humidity of the environment [1—3].

An important task is to minimize the spread of viral infection by airborne droplets in HVAC systems. The supply and exhaust systems of the centralized HVAC, which include a mechanical ventilation system with G4 coarse filters and a rotary heat recuperator, have become widely used in public and administrative buildings. The purpose of the HVAC systems is to maintain microclimate parameters (temperature, humidity, and chemical and microbiological composition of the air) in the premises within specified limits [4—6].

However, under certain conditions, the centralized supply and exhaust ventilation systems serve as a source for the accumulation and distribution of pollutants that are dangerous to human health, in addition, the air composition in the premise affects the course of the disease of an already infected person [7, 8].

According to the modern standards, the development of new or improvement of the existing HVAC systems should be aimed at reducing energy consumption and stimulating the use of renewable energy sources [9].

It should be noted that air is a multicomponent aerosol with a wide range of pollutants of both the natural and the anthropogenic origins. The quantitative and qualitative composition of the aerosol depends on the functional purpose of the premises, structural features, operating conditions, and climatic conditions. Therefore, the key factor for solving the urgent problem of safe air is the choice of a method for air purification and disinfection in the HVAC systems (Fig. 1).

With all the variety of available methods, the efficiency of their use in HVAC systems with significant air exchange is reduced because of the limited residence time of air pollutants in the area of influence of the cleaner.

In order to modernize the HVAC systems of buildings, given the anti-pandemic conditions, we need a set of measures, which includes the inactivation of biological pollutants, the destruction of light organic compounds, and the filtration of air from solid particles.

The methods of photocatalytic and plasma chemical air disinfection with a system of filters for catching solid particles and destroying excessive ozone have been the most widespread in today's conditions [10].

So far, not all the problems related to the efficiency of the photoplasmocatalytic methods in dynamic aerodisperse flows in centralized ventilation systems have been solved.

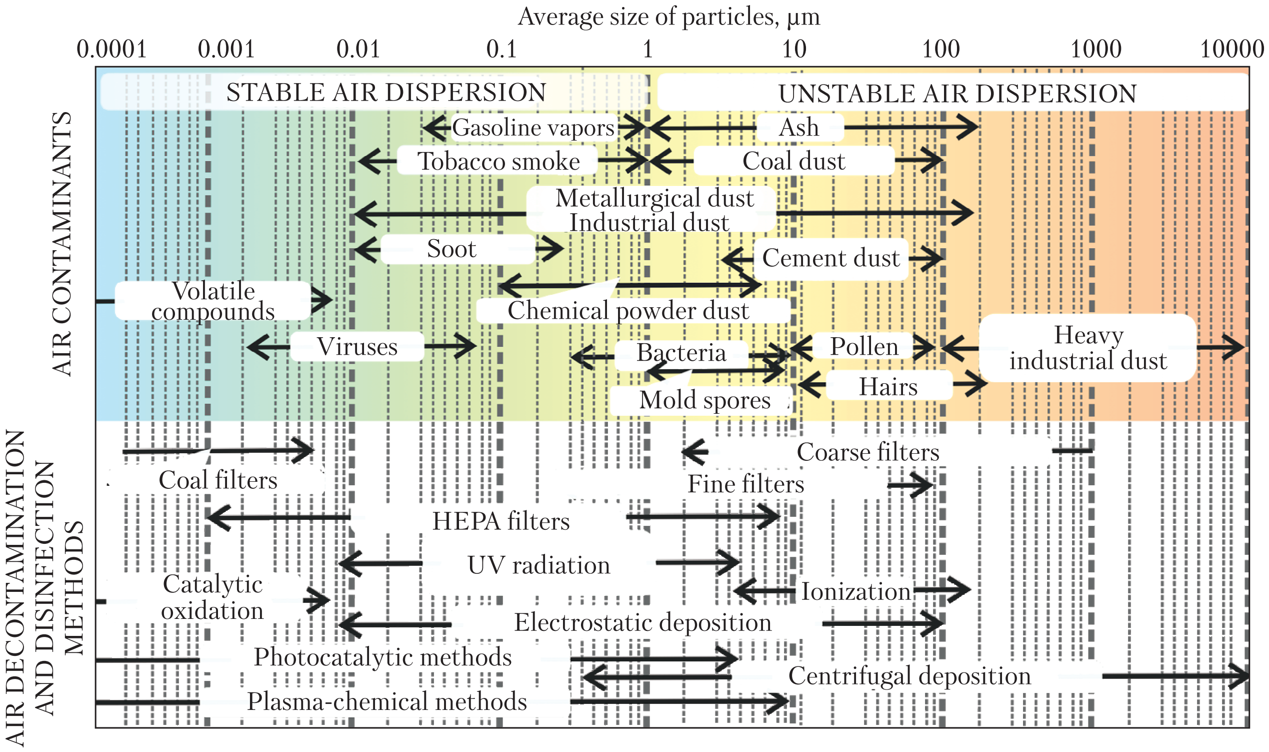


***Fig. 1.*** Disperse pollutants and methods for air purification and disinfection (based on [7, 10—17])

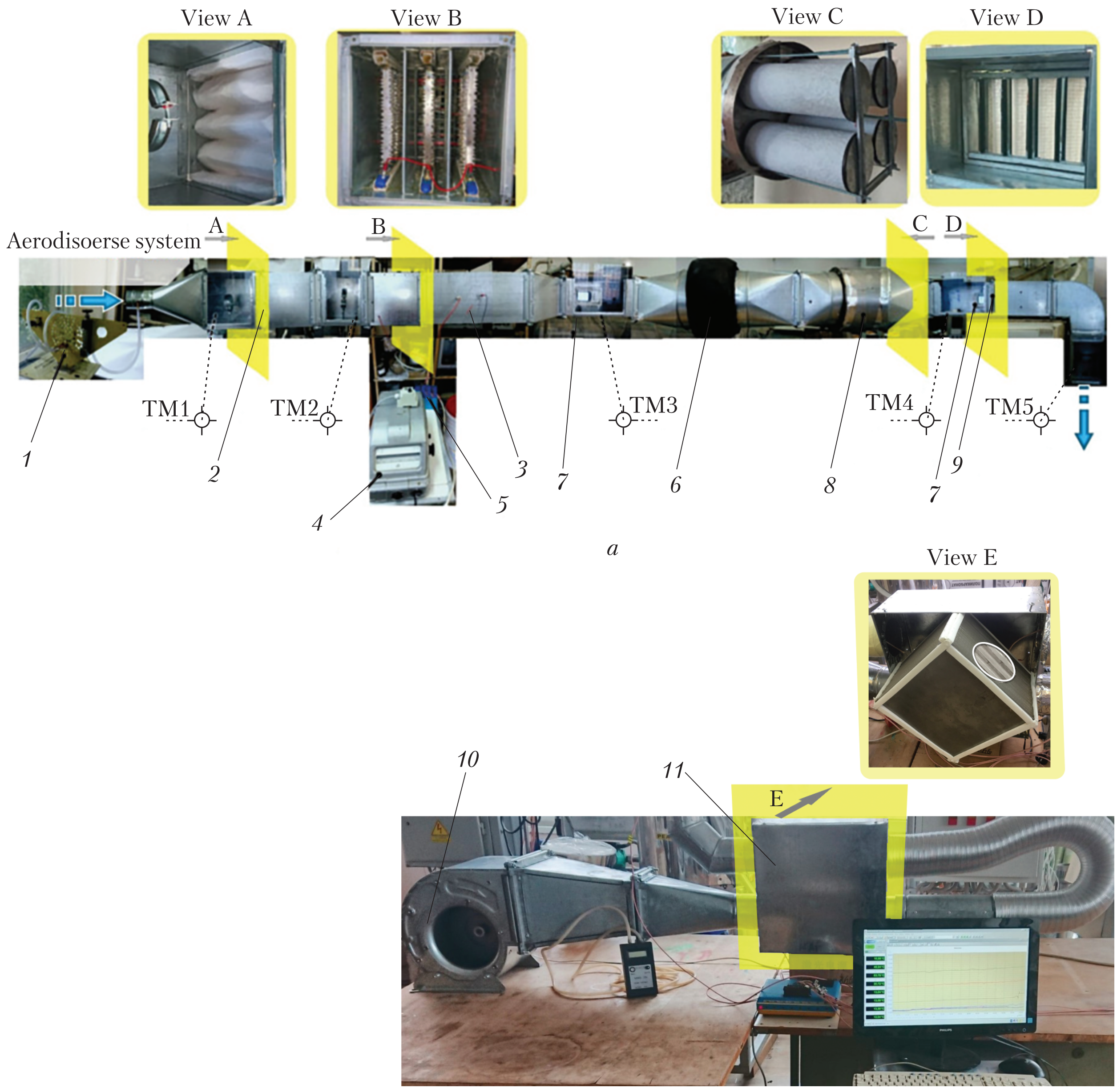
The plasma-chemical methods of decontamination are specific in terms of the mechanisms and kinetics of plasma-chemical reactions and chemical processes in low-temperature plasma and plasma jets when aerosolized flows pass through them [12]. Low-temperature plasma is formed under the action of a high-voltage discharge, the parameters of which depend on the time of interaction of the aerosol with the highly ionized space. Therefore, the intensity and duration of the effect of the ionized space on the molecules of organic compounds in the air flow depends on the configuration of the plasma-chemical air treatment unit.

During the conversion of harmful substances under the action of low-temperature plasma, there is formed an excessive ozone whose content in the purified air shall be reduced to a level below the maximum permissible concentration (MPC) in the working area (0.1 mg/m$^3$) [18—19].

The complex of key factors is determined by the efficiency of the ozone destruction mechanism in real conditions, whether it is photolysis, or thermal or catalytic mechanisms. The effectiveness of the ozone destruction process, depending on the mechanism used, is influenced by the following factors: the composition of the ozone-gas mix, the configuration of the adsorption unit, the condition of the contact surface, the power of radiation, the temperature, humidity, and air flow speed, as well as the surface properties of the catalyst [20—21].

The presence of photocatalytic filters in air purification systems has a number of additional advantages: economy (low specific energy consumption), environmental friendliness (decomposition into absolutely safe components for humans and the environment), and ease of maintenance.

The efficiency of photocatalysis of contaminated air depends on the configuration of the photocatalytic unit and the choice and location of the UV radiation source [13, 22], the aerodynamic resistance of the unit, the material of the carrier



*a*

*b*

***Fig. 2.*** Pilot installation for optimizing the parameters of the plasma chemical and photocatalytic air disinfection processes (*a*) with a heat recovery unit (*b*): *1* — module for dosage of sanitary-indicative microflora; *2* — coarse cleaning filter; *3* — plasma chemical treatment module; *4* — kilovoltmeter; *5* — high-voltage power supply unit; *6* — adjustable fan; *7* — air quality analyzer; *8* — adsorption-catalytic module (filter for neutralizing excessive ozone); *9* — photocatalytic module; *10* — centrifugal fan; 11 – plate recuperator; TM1...TM5 — air microflora monitoring points

matrix and the method for modifying its surface with a photocatalyst [22—25].

Usually, the issue of energy saving in HVAC systems is solved by introducing a recirculation air exchange scheme with the use of rotary heat recuperators [26—27]. However, in some European countries, there have already been made recommendations on the limitation of the operation of air con-

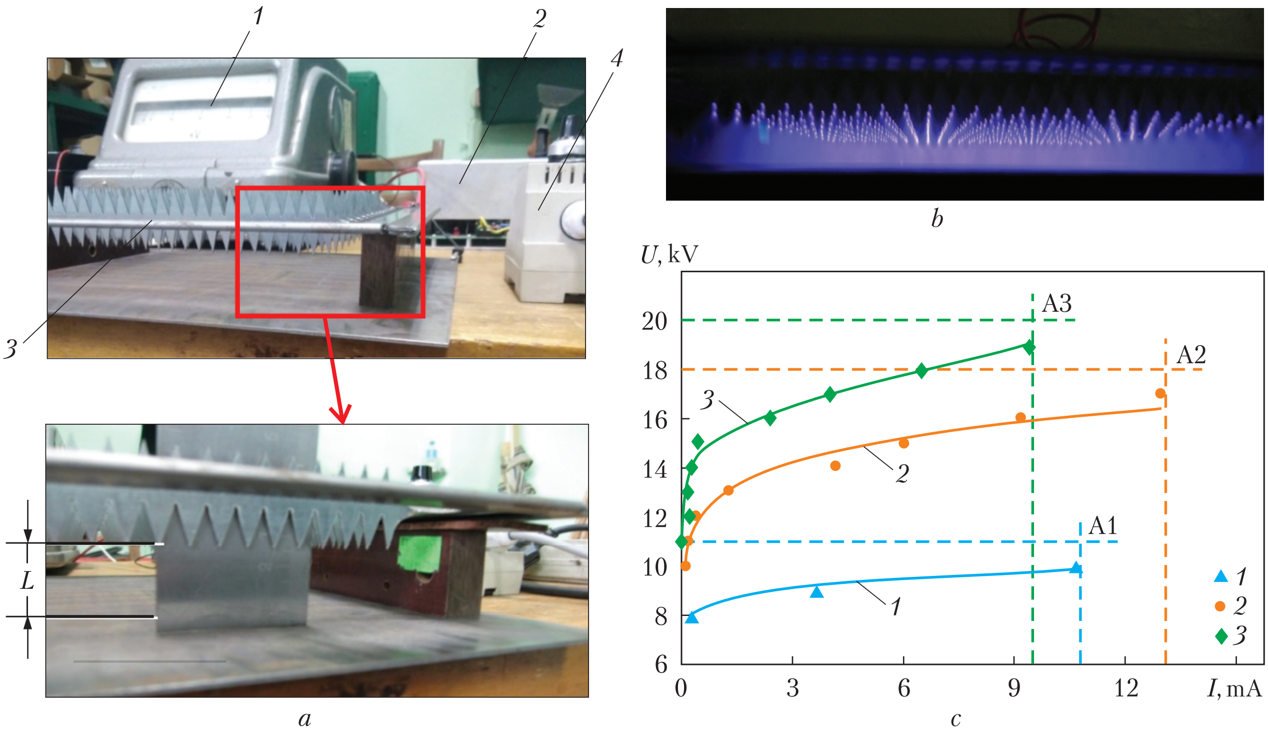


***Fig. 3.*** Studying the generator operating modes: stand (*a*): *1* — C96 kilovoltmeter; *2* — high-voltage source; *3* — low-temperature plasma generator section; *4* — control panel, *L* is the distance between the coronating electrodes; corona discharge in the plasma chemical cleaning module (*b*); generator's CVC under varying width of the arc gap; (*c*): *1* — 12 mm; *2* — 20 mm; *3* — 25 mm, A1, A2, A3 are the points of air gap breakdown

ditioning systems and the use of indoor air recirculation, although currently there is no harmonized international standard for the design of HVAC systems given the anti-pandemic measures.

The purpose of this research is to develop and create equipment for cleaning and disinfecting air from airborne pathogenic microflora in HVAC systems, which can be installed in the building's

*Table 1.* **Microanalysis of the Adsorption-Catalytic Granule Surface**

| Spectrum (Fig. 5, *b*) | C | O | Na | Mg | Al | Si | S | K | Ca | Fe |
|---|---|---|---|---|---|---|---|---|---|---|
| | % wt. | | | | | | | | | |
| 1 | 74.60 | 17.21 | 0.00 | 0.02 | 2.49 | 3.16 | 0.23 | 0.00 | 2.29 | 0.00 |
| 2 | 55.12 | 13.67 | 0.06 | 1.82 | 2.27 | 10.20 | 0.04 | 0.00 | 9.02 | 7.82 |
| 3 | 66.38 | 21.32 | 0.09 | 0.22 | 3.54 | 3.93 | 0.20 | 0.14 | 2.03 | 2.14 |
| 4 | 39.80 | 33.75 | 0.99 | 0.43 | 11.01 | 10.74 | 0.06 | 0.50 | 1.16 | 1.56 |
| 5 | 78.80 | 12.59 | 0.00 | 0.95 | 0.54 | 1.10 | 2.63 | 0.00 | 0.71 | 2.68 |
| 6 | 94.63 | 3.78 | 0.00 | 0.03 | 0.39 | 0.47 | 0.38 | 0.02 | 0.24 | 0.07 |
| 7 | 97.29 | 1.99 | 0.08 | 0.00 | 0.14 | 0.08 | 0.27 | 0.00 | 0.16 | 0.00 |
| 8 | 95.53 | 2.86 | 0.03 | 0.08 | 0.39 | 0.56 | 0.45 | 0.03 | 0.06 | 0.00 |
| 9 | 96.58 | 2.84 | 0.00 | 0.01 | 0.00 | 0.07 | 0.42 | 0.07 | 0.00 | 0.00 |

centralized ventilation system without its reconstruction. The developed HVAC equipment should reduce the microbiological contamination of the air environment to a safe level and contribute to reducing the risks of diseases transmitted by airborne droplets and airborne dust.

## DEVELOPMENT AND CREATION OF A PILOT INSTALLATION

Structurally, the equipment consists of autonomous functional modules (Fig. 2) that are mounted in the intersection of air ducts. Each module of the equipment is designed to clean the air from a certain class of pollutants and differs from each other in the principle of operation:

- The coarse air purification filter traps coarse particles from the air.
- The plasma chemical module is designed to decompose organic compounds into $CO_2$ and $H_2O$ at ambient temperature [12]. The products of high-voltage electric discharge (ozone, atomic oxygen, excited molecular oxygen, hydroxyl groups, and ions) have a high oxidizing capacity. The formed hydroxyl groups and ozone react with organic molecules, capturing hydrogen atoms and producing alkyl radicals that are subsequently quickly oxidized in the air flow. With this mechanism, they attack almost any organic compounds of living organisms. Most importantly, this mechanism destroys bacterial capsules and cell walls of pathogenic organisms. The cell membranes of organic molecules are destroyed as a result of bombarding them with electrons upon contact with the ionized plasma.

In the photocatalytic (PC) module, the air purification process goes through the following stages [28]:

- the adsorption of microorganisms and molecules of harmful substances on the FC surface and the generation of oxidizing agents on the photocatalyst surface under the action of UV radiation (365—405 nm);
- the destruction of the entire molecular structure of microorganisms as a result of the interaction of their organic matter with photoinduced radicals on the catalyst surface, which leads to their complete inactivation, and the deactivation of gas-chemical compounds and aerosols at the molecular level;
- the conversion of the entire substance of a microorganism or other dangerous pollutant into elementary inorganic compounds and harmless components.

## DEVELOPMENT AND COMPOSITION OF THE PLASMA-CHEMICAL AIR PURIFICATION MODULE

The main element of the module for aerodisperse plasma-chemical treatment is a low-temperature plasma generator that is connected to a high-voltage power source with an output voltage regulator.

To ensure a stable corona discharge burning process, several options of the geometry of the corona electrodes have been tested. The best indicators of the ionization and the density of electric field intensity in the zone of plasma chemical treatment have been obtained for the saw-shaped corona electrodes.

A bridge converter circuit with a capacitive divider is used in the manufacture of high-voltage source adjustable within the range of 0—30 kV. This ensures its stable operation in this voltage range.

An experimental stand has been created to determine the current dependence on the voltage of the crowning electrodes while varying the distance between them (Fig. 3, *a*). The parameters of stable operation of the low-temperature plasma generator (Fig. 3, *b*) have been determined based on the current-voltage curve (CVC) of the generator (Fig. 3, *c*).

The working range of voltage variation, at which the corona discharge burns and the air gap is ionized, is determined depending on the size of the arc gap between the electrodes *L*. The voltage increases until the ignition of the arc between the electrodes, which indicates the breakdown of the air gap and the termination of the ionization process. On the CVC, points A1...A3 (Fig. 3, *c*) show the beginning of the breakdown of the arc gap, depending on the distance between the electrodes and the voltage applied to them.

The results of experimental studies have shown that the distance between the electrodes significantly affects the stability of low-temperature plasma combustion. It has been established that an air gap length of 20—25 mm allows expanding the zone of stable burning of the corona discharge under varying high voltage supplied to the low-temperature plasma generator.

Structurally, the elements of the section for generating the corona discharge of the plasma chemical module are fixed in the case, forming a cassette (Fig. 4).

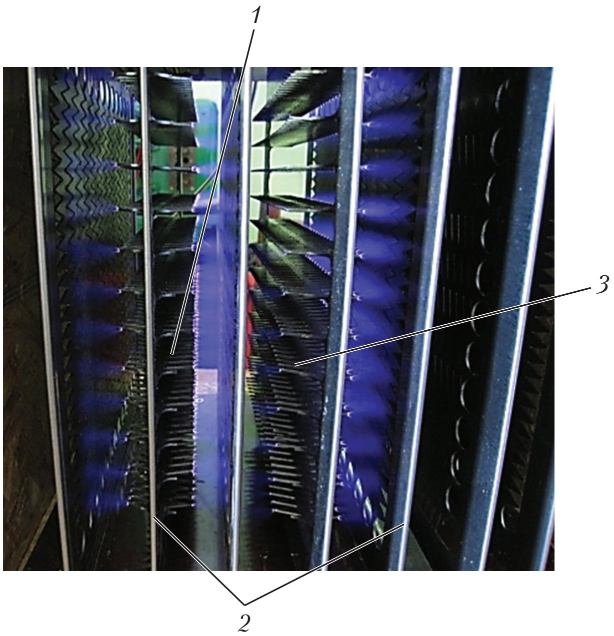


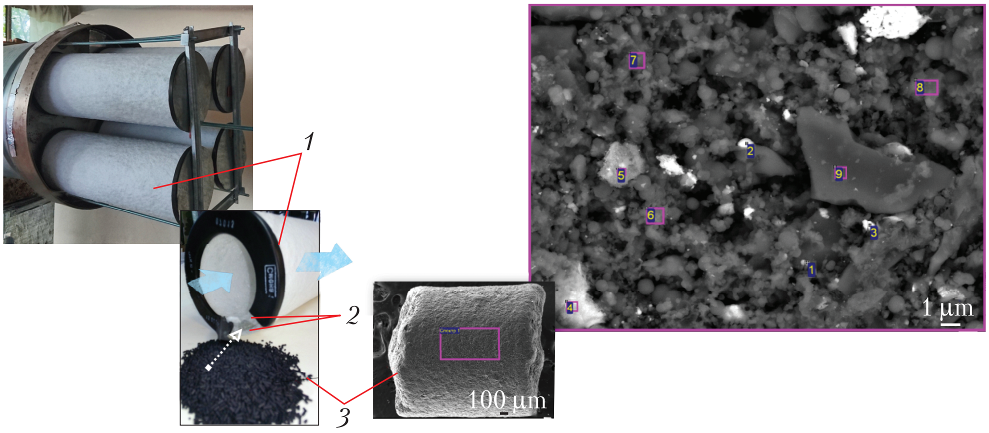
***Fig. 4.*** Low-temperature plasma generation module cassette: *1* — saw-shaped (coronating) electrodes; *2* — plate electrodes; *3* — corona discharge glow

The plasma chemical module with the following technical parameters has been developed:

- the voltage supplied to the low-temperature plasma unit $U = 20$ kV;
- the current supplied to the low-temperature plasma unit, $I = 9.8$ mA;
- the distance between the two electrodes, $L = 25$ mm;
- the electric field intensity between the electrodes $E = 8 \times 10^3$ V/cm.

After the plasma-chemical cleaning, the air flow enters the adsorption-catalytic module (Fig. 5) that is a set of cartridges placed in a box. The cartridge consists of two layers of class G filter material, the space between which is filled with adsorbent granules. The granule is formed from a mix of carbon particles and calcium aluminate.

Aerodisperse particles are electrified in the corona discharge zone, settle and are held electrostatically on the surface of filter layer 2 (Fig. 5, *a*). That is, the filter surface serves as a barrier against



*a* *b*

***Fig. 5.*** The adsorption-catalytic module: adsorption-catalytic module (*a*): *1* — cartridge; *2* — filter layers; *3* — adsorption-catalytic granular layer; granule at ×50 magnification and its surface morphology at ×5000 (*b*)

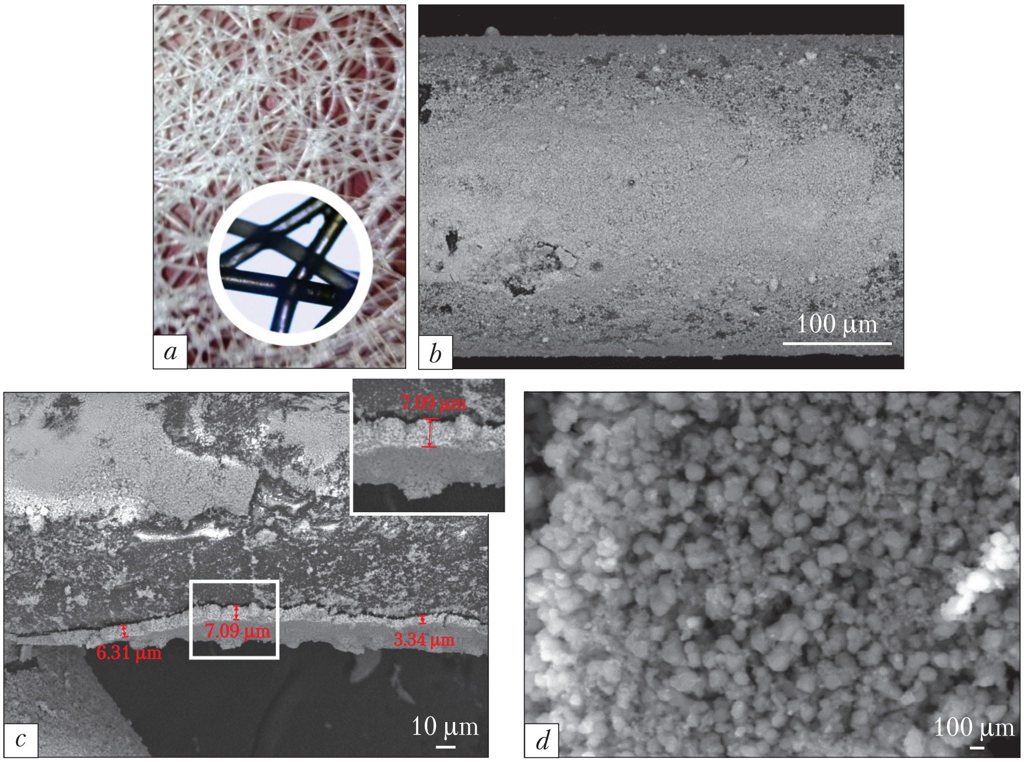


***Fig. 6.*** Initial PP matrix (*a*), SEM topography of the surface and the $TiO_2$ matrix coating section with magnification: ×270 (*b*), ×450 (*c*), ×30000 (*d*)

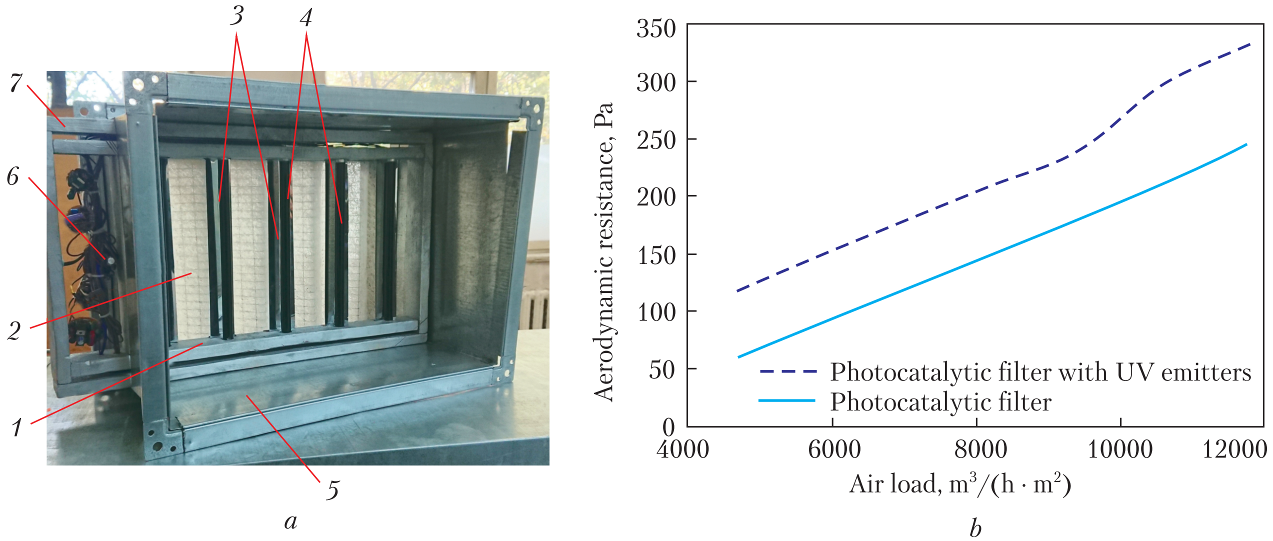


***Fig. 7.*** Photocatalytic air disinfection module (*a*) and its aerodynamic characteristics (*b*): *1* — PC-cassette; *2* — PC filter; *3* — UV radiation emitter; *4* — reflective screen; *5* — filter box; *6* — control unit for UV lamps; *7* — mounting frame

the ingress of solid particles onto the surface of the adsorbent catalyst 3. The porous surface adsorbs molecular compounds and molecules of excessive ozone and further degrades as a result of heterogeneous catalysis.

The catalytic properties of the adsorbent depend on how developed the granule surfaces are. When creating the adsorbent, we have analyzed the morphology of the granule surface, the uniformity of distribution, and the degree of dispersion of the mix components after the formation by the raster electron microscopy (SEM) method, on a JAMP 9500F Auger microanalyzer (JEOL Auger Micro Probe, Japan).

The research results (Fig. 5, *b*, Table 1) have shown a satisfactory distribution of mix component aggregates that form a predominantly mesoporous structure with an accessible internal surface, which contributes to the facilitated mass transfer of ozone-aerodisperse masses and reaction products. According to the Brunauer-Emmett-Teller (BET) method, the maximum specific area of the granule reaction surface is 380 $m^2/g^3$.

After the low-temperature plasma generation module, the aerodisperse mass is fed into the photocatalytic module and, having been cleaned, enters the premises.

## DEVELOPMENT OF PHOTOCATALYTIC (PC) AIR PURIFICATION MODULES AND MANUFACTURING TECHNOLOGY OF PC MODULES

In this research, highly dispersed crystalline titanium dioxide (10—45 nm) AEROXIDE® $TiO_2$ P25 (EVONIK Co.) with a specific surface area of 50 + + 15 $m^2/g$ has been used as a photocatalytic material, 80—90% of which has the anatase modification, with the rest (10—20%) having the rutile one [25].

A non-woven fabric made of polypropylene (PP) fibers that form a pore space (mostly larger than macropores) with an initial aerodynamic resistance of 10—30 Pa has been chosen as carrier matrix of the photocatalyst. It should be taken into account that in the course of surface modification, the micropores and partially the mesopores are be covered by a catalyst layer, which leads to an increase in the aerodynamic resistance.

The operational characteristics of PC filters depend significantly on the method for modifying the carrier matrix surface. As part of the research, a multi-stage technology with a full cycle of creating PC-modules on polypropylene (PP) membranes has been proposed. It includes the following stages: forming the geometry and composition of the matrix, modifying the surface of the carrier matrix with accompanying processes, equipping with UV emitters, and framing the photocatalytic module.

The carrier matrix consists of 2 layers of fibrous PP membrane, between which a metal frame is installed for structural rigidity. Thanks to corrugation with a 90° corrugation opening angle, a 1.4-fold development of the surface has been achieved.

Having formed the matrix, we apply photocatalyst to the surface. We have used the modification method that combines the methods of immersing the catalyst in a hydrogen dispersion at a fixed temperature and filtering through the porous part of the matrix, which are implemented in an innovative device of the PF-200 type, the operation of which is based on the principles of discrete-pulse energy input into heterogeneous systems [29, 30].

The structural and topological characteristics of the layer of AEROXIDE® $TiO_2$ P25 catalyst deposited on the fibers of the polymer carrier matrix (Fig. 6, *a*) have been evaluated with the use of the raster electron microscopy methods with an accelerated voltage of 10 kV.

Using the proposed technology for PP matrix modification, we have obtained a uniformly rough surface of the coating (Fig. 6, *b*, *d*) with a 5—10 μm thickness of the catalyst layer (Fig. 6, *c*). The corpuscular texture of the coating is formed by aggregated particles of applied titanium dioxide with a size of 80—160 nm.

The monodisperse aggregates form a predominantly monoporous space and create such a surface

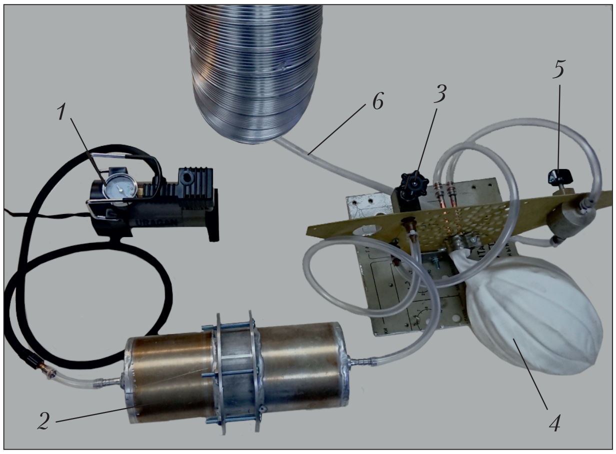


*Fig. 8.* Dosing module and supply of sanitary-indicative microflora into the air stream: *1* — air compressor; *2* — reactor with sanitary-indicative microflora; *3* — flow meter; *4* — contaminated air dosing unit; *5* — dosing valve; *6* — nozzle for supplying contaminated air

texture of the layer, which maximizes the access of UV radiation to titanium dioxide particles and allows the development of a photoreactive surface.

Structurally, the PC-module (Fig. 7) of the tablet type consists of a PC-filter and UV-emitters, which are mounted in a Z-line type frame. In the ventilation system, the PPC module is placed in the filter box for convenient maintenance and replacement.

UV radiation emitters *3* are located in such a way as to create conditions for illuminating the maximum area of the photocatalytic surface with direct light of sufficient intensity. The optimal radiation intensity on the photocatalyst surface ranges within 1.2—2 mW/cm$^2$.

The proposed design of the PC module provides for the illumination, by the reflected light, of polished aluminum screen *4* that reflects up to 80% of the light in the wavelength range from 300 to 400 nm.

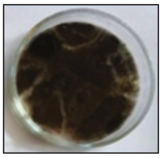
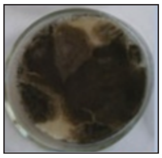
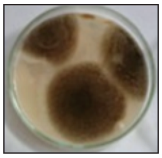
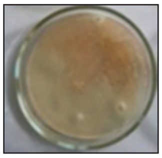
The proposed geometric parameters of the filter have made it possible to develop the contact surface and at the same time it does not lead to a significant increase in the aerodynamic resistance of the PC-module. The comparative analysis of the modified PC filter and the PC filter with UV emitters has shown a 1.3—2 times increase in the aerodynamic resistance, depending on the air load (Fig. 7, *b*).

## Development and creation of a recuperative heat exchanger

In centralized ventilation systems equipped with rotary heat recuperators, part of the air may flow from the exhaust duct to the supply duct. This creates conditions for the spread of pathogenic microflora throughout the premises of the building. The plate-type recuperators, in which heat is transferred through a heat-transfer surface, which makes it impossible for air flows to mix, are devoid of the mentioned disadvantages.

For the proposed air purification system, a polymer cross-flow plate recuperator has been designed and tested (Fig. 2, *b*). The heat exchange

*Table 2.* **The Aerodisperse System Properties at the Monitored Points**

| Viable colonies of mold fungi<br>The samples are taken<br>at monitoring points (Fig. 2, *a*) | <br>TM1 | <br>TM2 | <br>TM3 | <br>TM4 | <br>TM5 |
|---|---|---|---|---|---|
| Duration of operation of the cleaning system: 30 min | | | | | |
| Content of dispersed particles below 2.5 μm, μg/m$^3$ | 30 | 15 | 13 | 9 | 8 |
| Ozone concentration, mg/m$^3$ | 0.000 | 0.153 | 4.6 | 0.342 | 0.095 |
| Relative humidity, % | 58 | 58 | 58 | 57 | 56 |

surface of the recuperator is made of ribbed plates with a wall thickness of 0.15 mm and a rib height of 2 mm, which consist of a heat exchange package with cross channels of 6 × 2 mm. According to the results of the tests, the efficiency of the recuperative heat exchanger is 0.9 at an air speed in the channels of 0.75 m/s and decreases to 0.6 as the speed increases to 3 m/s.

### Creation of a dosing module for sanitary and indicative air microflora

The microbiological air pollution has been assessed by the methods of “bombardment” and sedimentation in an aerodisperse flow on the culture medium [31—33]. MPA (meat-peptone agar) is chosen as a culture medium (a standard medium used for the development of many types of microorganisms).

In the process of experimental studies, air is pumped through the experimental unit at a set speed. Petri dishes with culture medium are installed at the monitoring points (Fig. 2).

While conducting experiments with the help of the dosing module (Fig. 8) that is created as part of the research, we set the required concentration of sanitary-indicative microflora in the air and record the air quality indicators online.

In the research, we have estimated the inhibition of the growth of fungi of eukaryotic organisms (mold fungi) at each stage of decontamination of the aerosol medium.

Table 2 presents the data of the experiments in the regular conditions of operation of the ventilation system with the following parameters:

- the average speed of the airflow in the central duct is 5 m/s;
- the average air flow temperature is 17 °C;
- the voltage supplied to the ozone generation unit is 20 kV.

The samples of air microflora taken at the monitoring points are kept in a thermostat for 142 hours at a temperature of 37 °C. The qualitative and visually quantitative comparison of the samples (Table 2) has shown that with each stage of processing, the density and the number of colonies of mold fungi decrease.

The field tests of the developed equipment installed in an operating ventilation system with a rotary recuperator and forced air injection have been carried out in the autumn-winter period in a production room having dimensions of 24 m × × 12 m × 6 m (height). The air exchange multiplicity is equal to 2. The maximum number of employees who simultaneously stay in the production premises is 12 people. The average temperature and the relative humidity in the room are 14—16 °C and 65—70%, respectively.

The disinfection system is tested for 10 days during working hours. During the operation of the plasma-chemical and the photocatalytic air disinfection modules, air is sampled for the cultural environment at four points in the room, at a height of 1.5 m from the floor.

### THE AERODISPERSE SYSTEM PROPERTIES AT THE MONITORED POINTS

For the comparative analysis of the microflora content in the air, samples with the largest area of contamination after two days of exposure in a thermostat at a temperature of 37 °C are selected.

The results of microbiological studies of the air (Fig. 9) have shown that a decrease in the number of microflora is observed as early as after the first day of the operation of the equipment (Fig. 9, *c*). After the third day of the operation, no significant changes are observed in the selected samples.

During the tests, the microflora content in the indoor air environment decreased by 60% after 3 days of the equipment operation. Further, it almost does not decrease, which may be caused by the shortcomings of the design of the applied recuperator.

The results of the laboratory studies and field tests have showed that the depth and rate of inactivation of airborne microflora depends mainly on the volume concentration of atomic oxygen and ozone. The possibility of increasing the ozone concentration in the plasma-chemical air treatment

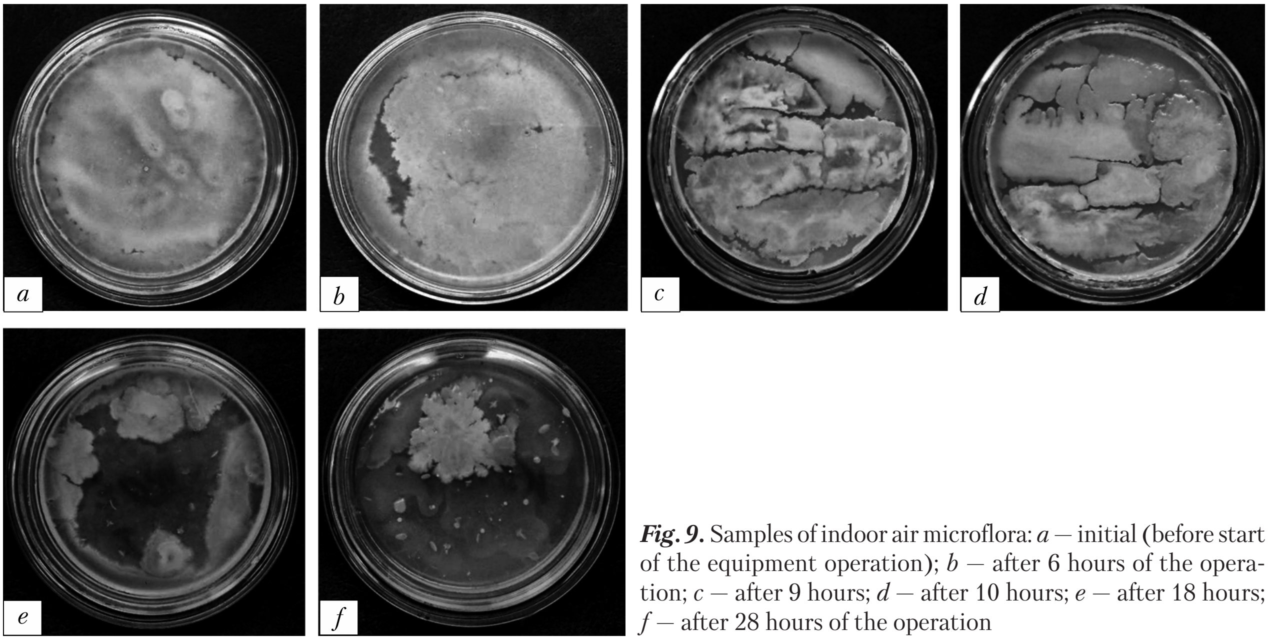


***Fig. 9.*** Samples of indoor air microflora: *a* — initial (before start of the equipment operation); *b* — after 6 hours of the operation; *c* — after 9 hours; *d* — after 10 hours; *e* — after 18 hours; *f* — after 28 hours of the operation

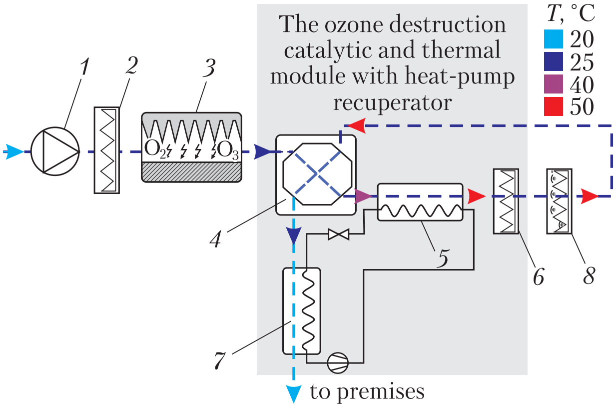


***Fig. 10.*** Block diagram of energy-efficient air cleaning and disinfection technology: *1* — discharge fan; *2* — coarse cleaning filter; *3* — plasma bipolar ionizer; *4* — heat exchanger (recuperator); *5* — heat-pump evaporator; *6* — adsorption-catalytic module; *7* — heat-pump capacitor; *8* — photocatalytic module

module is limited by the ability of the adsorption-catalytic unit to convert excessive ozone into molecular oxygen before supplying air to the room.

To intensify the decomposition of excessive ozone, it is promising to combine the catalytic method with the thermal method. Heating the air before feeding it to the catalytic filter helps to increase the efficiency of the ozone destruction process on the surface of the catalyst at a temperature above 50 °C [21]. In addition, keeping an elevated air temperature inside the device contributes to the decomposition of organic impurities accumulated on the surface of the catalytic filter [34]. The thermal decomposition of ozone by heating the air supplied to the catalytic filter is relatively simple in terms of process equipment. However, this process is energy-consuming and for this reason has not been widely used in HVAC systems.

The authors have developed an energy-efficient process chart of the air purification and disinfection process with a system of combined catalytic-thermal decomposition of excessive ozone (Fig. 10). Reducing energy consumption for air heat treatment is achieved by heat recovery from already heated purified air to the air that enters for heating. The use of a heat pump in combination with an air-to-air recuperative heat exchanger saves a significant part of the energy spent on heating and allows keeping the heating and cooling temperatures within the required limits. The implementation of the proposed air purification scheme allows reducing energy consumption for heating aerodispersion 7—8 times. The average efficiency of the recuperative heat exchanger is 0.65—0.70 and the conversion factor of the heat pump is 2.7—3.2.

Based on the results of the studies, we may conclude that air disinfection by the method of combined plasma-chemical and photocatalytic effect on the air flow with a system of catalytic-thermal decomposition of excessive ozone provides efficient cleaning from molecular pollutants and allows reducing the microbiological contamination of the air to a safe level, which contributes to reducing the risks of diseases transmitted by airborne droplets.

The efficiency of the developed equipment has been confirmed by the field tests to determine the stability of the operational characteristics of the proposed plasma-chemical and photocatalytic disinfection modules.

The implementation of the research results will make it possible to equip the existing ventilation and air conditioning systems of buildings with additional units for the inactivation and purification of air from molecular pollutants. There is an urgent need for this type of equipment in places of temporary stay of people (administrative buildings, shops, clinics, etc.) and in places of permanent stay (business centers, children's institutions, hospitals, etc.). This fact gives opportunities for the use of the proposed equipment in the systems of centralized ventilation and air conditioning.

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# РОЗРОБКА ОБЛАДНАННЯ ДЛЯ ЗНЕЗАРАЖЕННЯ ПОВІТРЯ В СИСТЕМАХ ВЕНТИЛЯЦІЇ ТА КОНДИЦІОНУВАННЯ ГРОМАДСЬКИХ БУДІВЕЛЬ МЕТОДАМИ ФОТОКАТАЛІЗУ Й ПЛАЗМОХІМІЇ

**Вступ.** Сезонні хвилі спалаху ГРВІ, зокрема й COVID-19, спричиняють потребу розробки комплексу заходів щодо створення безпечних для здоров'я умов перебування в місцях скупчення людей.

**Проблематика.** Наявні припливно-витяжні системи централізованого опалення, вентиляції і кондиціювання повітря (ОВіК) не лише не захищають від зараження, а й слугують джерелом накопичення та поширення патогенних мікроорганізмів. Пошук ефективних способів очищення повітря у місцях масового скупчення людей як складової протиепідемічних заходів є актуальним завданням.

**Мета.** Розробка та створення обладнання для очищення і знезаражування повітря від аеродисперсної патогенної мікрофлори в системах ОВіК, яке може вмонтовуватися в централізовані системи вентиляції будівель без їхньої реконструкції та зміни технологічних параметрів.

**Матеріали й методи.** Комплекс фізико-хімічних методів, які охоплюють аналітичне та експериментальне дослідження з використанням теорії електрогазодинаміки дисперсних систем та залученням методів растрової скануючої мікроскопії, методів порівняння однотипних якісних показників проб і вихідних зразків.

**Результати.** Для дослідження ефективності як окремих плазмохімічних і фотокаталітичних модулів, так і установки вцілому при режимах роботи, що моделюють умови експлуатації систем централізованої вентиляції, створено експериментальний стенд. Визначено оптимальні технологічні параметри процесів для підвищення ефективності знезараження й очищення повітря в ОВіК системах методами плазмофотокаталізу. Запропоновано технічні рішення для підвищення енергоефективності дослідно-експериментальної установки комплексного очищення і знезараження повітря від широкого класу забруднювачів повітря в системах припливно-витяжної вентиляції будівель.

**Висновки.** Знезаражування повітря методом комбінованого плазмофотокаталітичного впливу на повітряний потік із системою каталітично-термічного розкладання надлишкового озону забезпечує ефективне очищення від забруднювачів та дозволяє знизити ступінь мікробіологічної контамінації повітря до безпечного рівня.

*Ключові слова*: аеродисперсія, очищення повітря, плазмохімія, фотокаталіз, патогенна мікрофлора, ефективність.