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UV protection grating for UV reactors with gas flow

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An analysis of light-shielding protection grating designs (U-shaped, honeycomb, and louvered) for flow-through UV reactors revealed a contradiction between achieving a high level of UV radiation shielding and low aerodynamic drag. A louvered grating with angled lamellas complemented by straight inlet and outlet sections was proposed. Numerical modeling and experimental studies showed that the new design provides a level of UV radiation attenuation comparable to the best analogs, such as a U-shaped grating, while reducing aerodynamic drag by a factor of 9. Flow alignment in the UV reactor was achieved, noise levels were reduced to below 40 dB, and the reactor's dimensions were reduced without any loss of performance.

Keywords: UV radiation, UV reactor, UV disinfection, recirculator.

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Introduction

Flow-through gas UV reactors are widely used in different fields, including air disinfection in recirculating systems, removal of contaminating gases and odors, as well as conducting photochemical reactions. Recirculators with air disinfection with UV-radiation are widely used in medical institutions, food processing facilities, public and residential premises, as well as other crowded places. UV radiation occupies a leading position [1] among methods of air disinfection methods due to its effectiveness among a wide spectrum of microorganisms and the absence of formation of harmful by-products. Practical operation reveals a number of technical difficulties related to ensuring reliability and efficiency of UV recirculators. One of them is the need to shield UV radiation coming from the disinfection chamber for the protection of people against exposure. For this purpose, light-protective grids are used at the input and output of the reactor

with UV-radiation, the material and design of which have contradictory requirements. On the one hand, the grid must ensure safety by blocking the escape of UV radiation outside the unit's body. On the other hand, its structure should not impair the aerodynamic and acoustic (noise) indicators of system operation, at the same time, the material of grids should be resistant to UV radiation. An unsuccessfully designed grid creates significant aerodynamic resistance, can be a cause of low bactericidal efficacy and increased noise level during the system operation. Protective grids currently used in recirculators design have high aerodynamic resistance and create additional noise or insufficiently shield UV radiation.

The purpose of this study was to develop the design of light-protective grid of the UV reactor with a high degree of UV radiation shielding, low loss of airflow pressure, maintenance of uniform flow in the disinfection chamber and low noise level.

Geometry of the protective grid

Recirculators use several types of light-protective grids: grids based on embedded U-shaped profiles [2] (fig. 1a); louvered grids with wave-shaped lamels (fig. 1b); honeycomb filters made of sheet metal (fig. 1c).

U-shaped grids demonstrate the maximum UV radiation shielding efficiency compared to louvered and honeycomb ones. However, the trajectories of air flows in such grids include two consecutive 180° turns, which in combination with local velocity increase in the channels leads to significant loss of head.

Honeycomb metal filters have lower aerodynamic resistance than U-shaped grids. Loss of head in the honeycomb filter are related to the interaction and friction of differently directed jets at the grid outlet, as well as with energy dissipation of turbulent vortices at the result of their contract with the reactor walls and

surrounding jets. The geometry of honeycombs in most cases excludes the straightline passage of UV radiation, however, there is a critical angle of rays incidence for them, at which the number of internal reflections is insufficient for effective weakening of UV radiation.

Louvered grids have a low aerodynamic resistance, however, they do not always provide a required level of UV radiation shielding. To increase the level of UV radiation absorption, the lamels of grids are covered with absorbing coatings (paints), however, under prolonged exposure to UV radiation they are destructed with emission of resulting products into the air stream [3]. Currently used shape of lamels sets the flow direction different from the normal to the grid's plane which results in flow breakdown from one of the walls of the UV reactor chamber, causes the formation of turbulent zones and unequal distribution of velocities in the reactor's displacement volume.

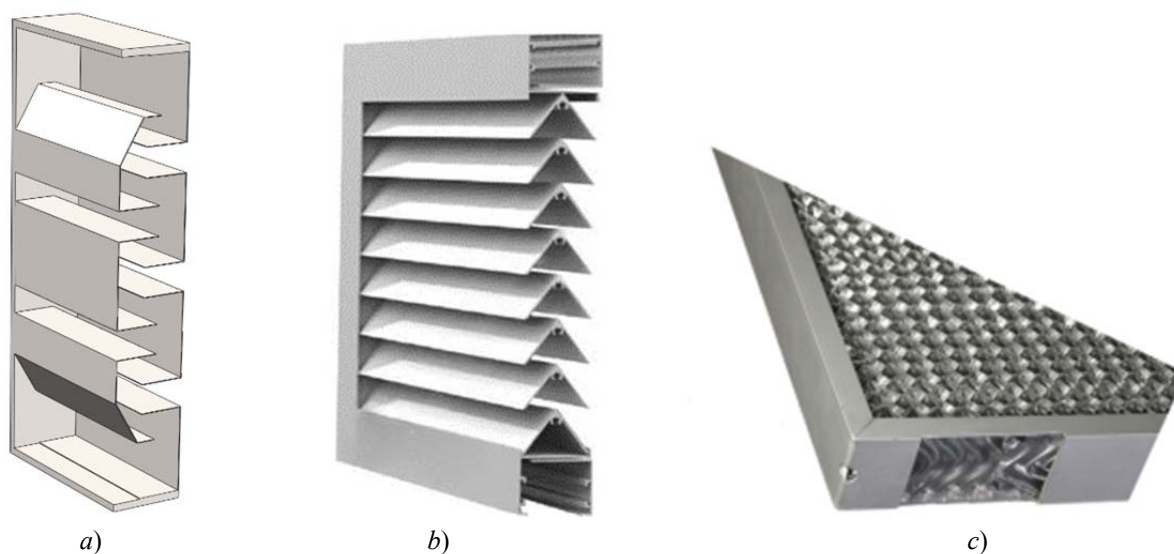


Fig. 1. Types of grids. a) – U-shaped, b) – louvered, c) – honeycomb

Non-uniformity of the field of velocities in the reactor's working chamber results in significant variation in the residence time of various parts of the air stream in it. Part of microorganisms goes through the radiation area in a time different from calculated time and receive a radiation does lower than required threshold which does not ensure their inactivation. As the result, the total disinfection efficiency of the recirculator decreases. To compensate for the decrease in compensation efficiency, it is required either to increase the

power of UV lamps or to decrease the flow rate to increase the exposure time, which reduces the unit performance. The structure of grids and the reactor must ensure not only the blockage of UV radiation but also equalizing air flow behind the grate.

As part of the analysis of existing structures, a louvered-type grid scheme was created for further development. To achieve the set goals a new lamel profile was developed with is an angular V-shaped structure with added straight-lined inlet and outlet sections direction

along the air channel of the system. Functional purpose of these areas is as follows:

1. The inlet area is designed for segmentation and stabilization of incoming flow before it moves into the labyrinth part of the profile which contributes to the decrease of turbulence generation inside the grid.

2. Outlet section ensures the orientation of the airflow along the disinfection chamber axis after passing the labyrinth, minimizing the jet deflection onto the chamber walls.

3. Additional straight-line sections increase light-protective characteristics by increasing the number of rereflections in the interlamellar space of the grids and creating additional shielded areas of UV radiation trajectories.

Numerical modeling

At the first stage, numerical modeling of hydrodynamic and optical characteristics of two types of light-protective grids was conducted: a traditional structured based on U-shaped profiles and developed grid consisting of angular lamels with additional straight-lined sections.

Hydrodynamic modeling was conducted using the finite-volume method (CFD-modeling by FVM method with RANS [4] turbulence model). Borderline conditions for CFD-model were set as follows: dimensions of the air duct 250 mm × 300 mm; a uniform flow velocity of 1 m/s is set at the outlet; static pressure equal to atmospheric pressure – at the inlet; channel walls were considered smooth and impenetrable, and the roughness of 1 μm was considered for grids surface; linear dimensions of computational cell were 1 mm. Both grids were modeled in the same overall dimensions. Geometrical parameters of light-protective grid with U-shaped profile are shown in the left part in fig. 2a, louvered grid – in fig. 2b.

The program of numerical modeling provided for:

1. Visualization of flow patterns and velocity vector fields;

2. Calculation of velocity distribution in the cross section at a distance of 100 mm behind the grid;

3. Determination of the difference value of the total pressure on the grid;

4. Calculation of attenuation coefficient of the UV radiation by grids.

Results of CFD-modeling of flow trajectories in the grid and on the reactor are shown in fig. 2. Fig. 2a shows the distribution of flows with grid with U-shaped lamels profile, fig. 2b – a grid with lamels with the structure designed in the plane of symmetry of the problem. The grid with P-shaped lamels is characterized by wider velocity spread, occurrence of vortices and development of turbulence at the grid outlet which resulted in local increase of flow rate in the disinfection chamber, as expected based on the flow conservation equation. Open area at the outlet for grid with U-shaped profiles was 20 % of the channel cross section, which is the reason for a local increase in flow rate at the grid's outlet by 5 times relative to the velocity behind the grid. Open area at the grid outlet with angular lamels is 90 % of the channel cross section, so the air flow rate at the outlet of the grid channels is increased only by 10 % compared to the velocity in the channel. There are no vortices behind the grid, the flow velocity profile is fairly uniform. Mean square deviation of the velocity at the distance of 100 mm from the grid outlet was 1.03 for the grid with U-shaped lamels and 0.27 for the grid with angular lamels. Differential pressure for grids with U-shaped lamels was 81.1 Pa, and for the grid with angular once only 12 Pa.

Calculation of light-protective properties of grids were conducted by ray tracing method. For ray tracing, models were used that consider the reflection coefficient of UV radiation with a wavelength of 254 Nm and combined diffuse-specular nature of reflection from surfaces. Results of modeling of UV radiation distribution show that the grid made of angular lamels ensures an average shielding in the output plane comparable to that in the case of using grid with U-shaped lamels. At the same time, the peak values of radiation behind both grids are at the same comparable level. Design average attenuation of UV radiation (averaging of the cross-sectional area of the air duct) defined as $\lg(E_0/E)$, where E_0 and E are exposure rates without and with grid, respectively, for U-shaped grid it was 3.50, for grid with angular lamels – 3.44, which is enough to provide safety.

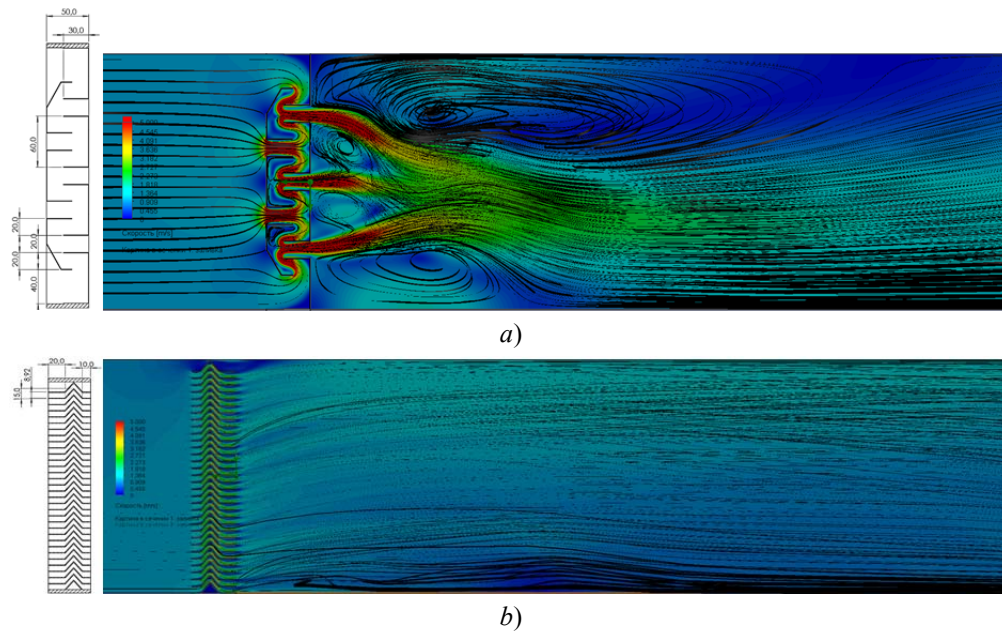


Fig. 2. Trajectory of flows in the grid and reactor: a) – U-shaped grid; b) – louvered. Air flow from left to right. Geometry of grids is shown on the left

Comparison with the experiment

Experimental verification of the results of numerical modeling was conducted at the second stage of the study. Differential pressure was measured in the air duct with cross-section identical to the calculation model with installed metal light-protective grids. A centrifugal fan located at the channel output was used to create air flow. Regulating flow rate in the range of 0.3–1.8 m/s, respectively, was conducted using a PWM controller, regardless of the type of the installed grid, the velocity measurement was conducted using Testo 417 anemometer. Measurement of differential pressure on the grid was performed by digital differential pressure gauge. Measured differential pressure values depending on air velocity in the channel are shown in fig. 3.

As follows from fig. 3, up to the air flow velocity $v = 0.6$ m/s, pressure differences on both grids differ insignificantly. Starting from a velocity of 0.8 m/s, U-shaped grid had a multiple higher resistance than an angular one. At a flow velocity of 1 m/s, the differential pressure on the angular grid is 5 Pa, and on the U-shaped grid the interpolated value is 48 Pa. Thus, by using protective grid with angular lamels for the reactor with gas flow, it is possible to reduce the pressure drop by an order of magnitude at flow rates of more than 1 m/s.

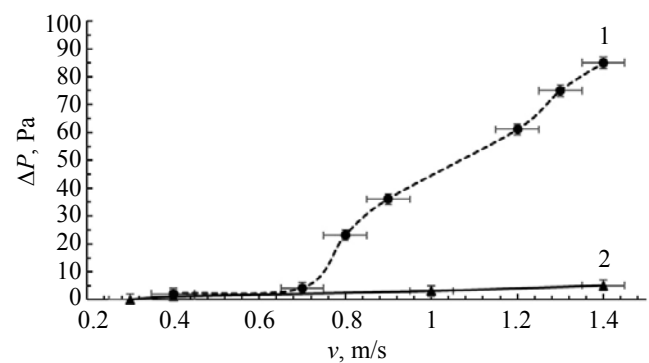


Fig. 3. Dependence of differential pressure ΔP , Pa upstream and downstream of the grid on the air velocity. 1 – grid with U-shaped profiles, 2 – angular grid

Flow breakdown on the fan blades is one of the main sources of aerodynamic noise in air duct systems, since the turbulent vortices that appear during the process cause pressure fluctuations and, consequently, sound waves [5]. The reduced grid resistance made it possible to reduce the overall pressure drop in the recirculator which resulted in the decrease of noise from the device, since the fan created a lesser pressure drop in the chamber which led to a decrease in the number of flow breakdowns on its blades. The noise reduction effect was measured using method recommended by GOST R ISO 3744-2013 [6] for two test reactors having the same dimensions and fans but different light-protective grids. The system with two U-shaped grids had a noise level of 42 dB, and the system with the proposed angular grids – 36 dB. It is worth noting that the

noise level from devices in different institutions is strictly regulated, for example, in hospital wards and operating theaters, the noise level should be lower than 40 dB [7].

To measure the light-protective efficiency of the grids in the air duct, a U-shaped UV lamp with a power of UV radiation of 33 W at a wavelength of 254 nm was placed in 100 mm from the open end, and the test grid was installed at the channel's output. Measurement of initial irradiance without grid was conducted using ILT2400 digital radiometer in the plane located at a distance of 100 mm from the channel edge perpendicular to its axis along a grid of 5×9 points. After the test grid was installed on the open pipe edge, the measurements were repeated at the same points. The light-protective efficiency was determined by the attenuation coefficient, as the logarithm of the ratio of the irradiance values at the points before and after the installation of the grid. For U-shaped grid the average attenuation was 3,88, and for the angular grid – 2,97 which complies with calculations for ray tracing model. Thus, angular grid with such attenuation ensures a reduction in UV intensity to values not exceeding the permissible levels defined in SanPiN 2.2.4.3359-16 [8].

Conclusion

The proposed design of light-protective grid with angular lames with additional plane guides which is significantly superior to the existing analogs for UV reactors with gas flow. The

measured degree of UV radiation shielding with a wavelength of 254 nm was 2,97 which is comparable to the attenuation degree of the best sample of light-protective grids, and aerodynamic resistance at flow rates of 1 m/s is reduced by an order of magnitude compared to the widespread grid with U-shaped profiles. Moreover, angular grid with additional straight-lined guide sections stabilizes the flow in the UV reactor chamber and minimizes its separation and reduces velocity variation to the mean-square deviation of 0.27. Currently used grid with U-shaped profile creates strong spatial deviations of the flow behind the grid, occurrence of vortices and large velocity inhomogeneities in the reactor chamber with mean square deviation of velocity at a distance of 100 mm from the grid's outlet equal to 1.03. Such differences are explained by a fourfold increase of open area of angular grid compared to the U-shaped one and presence of straight-lined guides. The noise level was reduced to 36 dB which is lower than the threshold level 40 dB according to SanPiN [6] without loss of performance which was previously impossible when using U-shaped light-protective grids with noise level of 42 dB. A more stable gas flow is obtained in the radiation chamber of the UV reactor which increases the efficiency of air disinfection. The use of improved light-protective grids made it possible to increase the air velocity in the reactor which allowed to halve the overall dimensions of the recirculator. The proposed design is used in serial devices of NPO "LIT" UV circulators.

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