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Research Article,

The Efficiency of Screw Channels in Metamaterials for Pathogen Decontamination under Ultraviolet C Radiation

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Abstract:
The main idea of new equipment is connected with the rotation of contaminated fluid by screw channels of meta-materials, prepared from UVC fiber/spherical optics in order to improve the decontamination efficiency. © 2022 The Author(s)
OCIS codes: 120.3890 Medical optics instrumentation, Meta-materials; Evanescent zone; Decontamination; Viruses and bacteria, spinning effect

Introduction and Main Idea:

Pathogens (viruses and bacteria) can reach the organism not only through transmission traditional mechanisms like direct contact with other persons but in the last time is observed the positive correlation has been observed between the spread of the virus and fluids (water or air) pollution [1]. COVID-19 could have an air/water transmission trough particulate matter could create a suitable environment for transporting the virus at greater distances than those consid- ered for close contact. SARS-CoV-2 is an enveloped virus $0.1\mu m$ in diameter. Viruses are often transmitted through respiratory droplets produced by coughing and sneezing. Respiratory droplets are usually divided into two size bins, large droplets ($> 5\mu m$ in diameter) that fall rapidly to the ground and are thus transmitted only over short distances, and small droplets ($< 5\mu m$ in diameter). Small droplets can evaporate into 'droplet nuclei', remain suspended in air for significant periods of time and could be inhaled [2]. As a usual they are not transparent in UVC decontamination dia- pason (200-280 nm) and needs a more near action of such radiation obtained from traditional sources from all direction to such droplets in order to achieve a good effect.

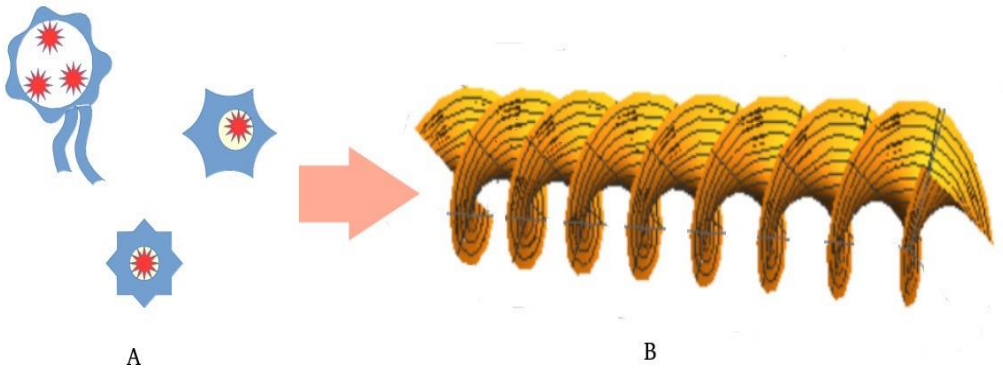

Fig. 1. The contaminated by pathogen droplets (A) with dimensions about 10 $100nm$ can be pumped and imposed under rotation acceleration between free space of helical ensemble of the scrolled fibers (B). Achievingthe evanescent zone of UVC radiation of each fiber the pathogens can be effectively inactivated.

The main idea is connected with the rotation of contaminated liquids and gases by screw channels of meta-materials, prepared from UVC fiber optics in the torsion configuration represented in the Figs. 1 and 2. The contamination liquids are rotated along the flow direction. Considering that the density of virus and bacteria droplets are larger than the density of liquids, the adherence of the pathogens to the "external surface" of the rotation channels increases as a function of the torsion degree of channels [3, 4]. As the number of such rotation canals in the proposed meta-material is large, the total surface consists of the sum of the surfaces of each flow canal between the fibers. This UVC decontamination effect depends on the inertial centrifugal force, which appear on the droplets infected by pathogens during its rotation flow along the channel. The large density of pathogens gives us the possibility to find the connection between its flow velocity and spinning radius of rotation channel. The centrifugal force must pull the pathogen droplets to the fibers/sphere surface penetrated by evanescent UVC radiation in the flow channel during the spinning effect (see Fig. 2). This UVC decontamination effect depends on the inertial centrifugal force, which appears on the pathogens duringits rotation flow along the channel.

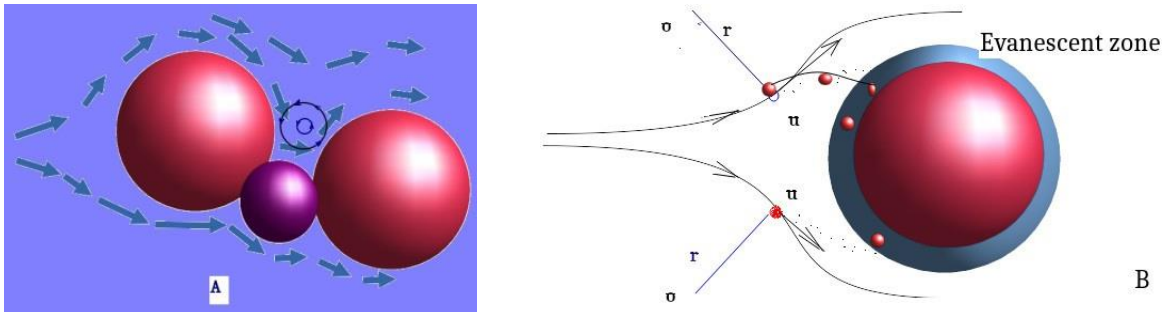

Fig. 2. The acceleration of the pathogens around the elements of meta-material and possible turbulent flow withthe acceleration of the pathogens in the circle or Screw Channels in the three-dimension case (see fig *A* and *B*).If the density of the pathogens is higher than the density of the fluids the viruses or bacteria can stick to the surface of spheres of metamaterial elements penetrated by ultraviolet C radiation.

Considering that the density of the pathogens, ρ_p is larger than the density of fluids, ρ_f . The centrifugal force, $F = (\rho_p - \rho_f)\omega^2 r$ which acts on the pathogen along the rotatory radius, r, with frequency ω in the rotational acceleration represented in the Fig. 2*B* must be compensated by resistance force opposed by the fluid, $\beta dr/dt$, when the rotation radius increases. Taking this into consideration the projection of the second Newton law on the radius direction may be approximated by the expression $\rho_p \omega dr/dt = (\rho_p - \rho_f)\omega^2 r - \beta dr/dt$. Or in this description radius increases as the function of time in the $r(t) = r_0 \exp[(\rho_p - \rho_f)\omega^2 t/(\rho_p \omega + \beta)]$.From which follows the pathogens deflects from the flows lines achieved the UVC evanescent zone of the elements of metamaterial represented in Fig. 2. This estimation demonstrates why the quick decontamination effect may be achieved with higher efficiency in the dynamic situation in comparison with static representation. The decontamination efficiency substantially increases in the moving pathogens together with liquids (or infected aerosols in flow gazes) between the elements of metamaterials in comparison with quasi-stationary decontamination regime. This effect may give substantially contribute to the turbulent flow of fluidsFig. 2 *A*.

Experimental Results:

It is complicated to use pathogens in the decontamination procedures in the physics laboratory. But taking into consid- eration that the big number of pathogens are sensible to UVC radiation than eukaryotic cellular structures, we have to substitute these contaminated fluids with yeast solution, which has larger resistance to UVC radiation in comparison with many viruses or bacteria. In this approach, the improving of the inactivation rate of the yeast colony using this type of metamaterial will mean that this efficient method will work successfully well in the case of prokaryotic cells specific for many bacteria.

Fig. 3. The decontamination core (C) filled up by scrolled fibers (A or balls (B). All system of lamps and decontamination core is introduced in the big aluminum cylinder with diameters about 20 cm represented in Fig C.

For obtaining good experimental results was take $2.1L$ of water in which was dissolved $80Gr$ of yeast and added $440Gr$ of sugar. After some Min the dynamical (see Fig. 4) and static (see Fig.5) experiments began. Our decontami- nation core with 0.8 M length and 2.5 cm in diameter is filled up with a diameter of spheres about $0.5-1mm$ of the

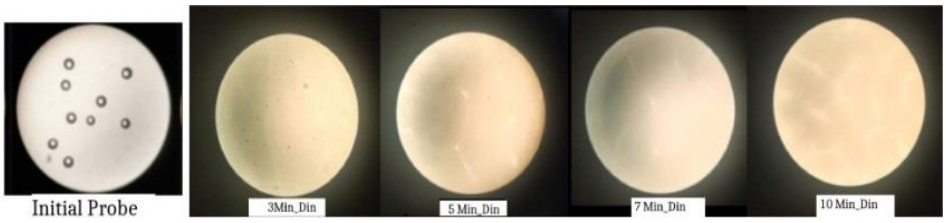

Fig. 4. The decontamination procedure of $1.5L$ of yeast solution in which the fungus colonies was measured after 3, 5, 7, and 10 Min in dynamic regime. Beginning with 7 and $10Min$ the fungus colonies are not observedwith our optical microscope. We mention that during the cyclical pump of $1.5L$ of solution through the meta- material element of our equipment only $0.15L$ part of the solution was under the UVC radiation. The remainingpart was in the cyclical moving.

Quartz material. The core is covered by 6 mercurial lamps which a maximum of radiation is 250-260 nm. To improve the efficiency of UVC radiation all the system is placed in the aluminum cylinder with the diameter about $20cm$ so that the intensity of the radiation in the center of the big cylinder increase significantly due to the reflection proprieties of the aluminum. More than this the researchers and people from the room are well protected from the direct action of UVC radiation obtained from 6 lamps represented in the Fig.3.

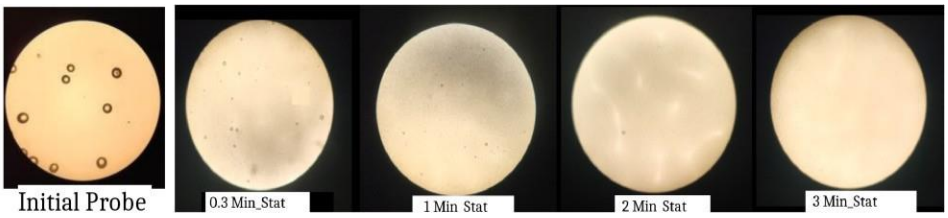

Fig.5. The inactivation of fungus from the yeast solution in the static regime under the direct UVC expositionof a small quantity of water $0.15L$ during the time intervals: $0.3Min$, $1.0Min$, $2Min$, $3Min$. It is observed that atthe beginning with $3Min$ of exposition the fungus colonies are totally deactivated.

Conclusions:

The decontamination efficiency is connected with the rotation of contaminated liquids and gases by screw channels of meta-materials, prepared from UVC fiber optics (or close packed spherical elements of metamaterial) in the torsion configuration. The contamination liquids are rotated along the flow direction. Considering that the density of viruses and bacteria (or droplets, aerosols contained they) are larger than the density of liquids, the adherence of the pathogens on the rotation channels increases as a function of the torsion degree of the channels. As the number of such relative canals in the proposed meta-material is large, the total surface consists of the sum of the surface of each flow canal between the fibers.

We estimated that for inactivation of 2, 5*L* of fungus solution we need about 5*Min* of UVC radiation in the cyclical rotation of the fluid through our decontamination equipment. In the static regime for decontamination of 0.15*L* of fungus solution we need 3 min UVC radiation. This comparison means that for decontamination of 1.5*L* of fungus solutions in the static regime we need 10 times more the decontamination time. For example in dynamic regime we used about 3*Min* for 1.5*L* instead of 30*Min* in the static one for the same quantity of contaminated. This estimation demonstrates that the dynamical regime with the mean velocity of fluid through the decontamination were equal to 30 60*Cm/Sec*, to give us the 10 times of the increases of decontamination rate. We consider that in the turbulent flow the rate may increase drastically on the decontamination efficiency.

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