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Analysis of possibilities decreasing toxicity of the virus SARS-CoV-2 by acoustic methods

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Abstract:
The aim of the study is to analyze the possibility of reducing the toxicity of air, in which viruses (including SARS-CoV-2) and other pollutants are dispersed, using acoustic methods. Under the influence of an acoustic wave, particles in the air undergo a certain movement, a kind of displacement, called drift. This effect is activated by the mechanism associated to the nonlinear propagation of acoustic waves. Drift forces depend on the position of the particles, their size and the parameters of the acoustic wave and the medium they spread in. In the process of the impact of acoustic waves, the average size of suspended particles increases. The agglomeration may occur between small particles creating larger particles. The agglomeration can occur due to the acoustic and orthokinetic mechanisms. The interaction of acoustic waves with pollutants scattered in the air is most effective for a few micrometers in particle sizes. In the process of acoustic influence the mean particles increases. The particles collide and agglomerate due to the interactions induced by sound waves. Enlarged particles (viruses including SARS-CoV-2) they can no longer penetrate the human lungs. The particles with diameters smaller than a few micrometers are especially dangerous for man's health. Therefore, acoustic waves with appropriate parameters can be used to reduce air toxicity.

Key Word*: Acoustic waves; Polluted air; Coronavirus; SARS-CoV-2; Virus size; Acoustic aerosols agglomeration.*

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I. Introduction

The review of the research results of the discussed issue in the literature available indicates a wide use of acoustic waves in technical as well as medical applications [1,2,3,4]. Institutions engaged in the protection of the nature point out that the particles with diameters smaller than a few micrometers are especially dangerous for man's health [5,6].

The present-day lifestyle, particularly living in a dusty, polluted environment is especially dangerous to human health [7]. In this work it was performed theoretical analysis of acoustic field influence on processes proceeding into two-component medium which is polluted air (suspended in the air droplets, viruses, including coronavirus, dust particles). Acoustic field causes to accelerate particles coagulation process.

A serious threat is toxic dust that enters the lungs and settles on the bronchioles, damaging the lungs. It is therefore extremely important to properly protect the respiratory tract against the risk of inhalation of tiny-particle dust and pollution. In order to ensure adequate, effective respiratory protection, the size and type of airborne pollutants must be taken into account. Contaminants in the air inhaled by humans come in various forms, such as aerosols and suspensions. The effects of harmful substances actions depend on several factors, such as the type of inhaled substance, concentration and duration of exposure. Aerosols are tiny particles floating in the air that can be solids, liquids or their suspensions. A very important role in the deposition of particles in the respiratory system play size of particles, density, shape and aggregation. The size of particles suspended in the air ranges from 0.01 μm to 100 μm and determines the place where a given dust particle will be captured in the respiratory system.

Obviously, the human body has its own defense capabilities against pollution. Nasal hairs that allow larger particles to be retained before they penetrate deep into the respiratory tract and sneezing which helps to keep the airways clean. Additionally, the sticky mucus that covers the respiratory tract traps air pollutants larger than a few micrometers. They are removed thanks to the movements of cilia located in the respiratory tract. This movement causes the movement of mucus up the respiratory tract. The airways are also cleared during coughing, which causes air to be ejected from the lungs [8].

A number of viruses are constantly floating in the air. Transmission of viruses through the air is the predominant route of transmission of viruses, droplets and aerosols [8]. *SARS-CoV-2* can spread from person to person via tiny droplets from the nose or mouth that spread when a person coughs or exhales.

During activities such as exhalation, coughing, sneezing and speaking, aerosols and droplets contaminated with virus particles are formed. Depending on their size and environmental conditions, such particles are capable of living in the air for different periods of time and can cause infection. Some studies have been conducted to determine the mechanism, aerodynamics of molecules and droplets containing viruses causing infection [9]. Particles as small as viruses can remain suspended in the air for a long time. People close to the source and those at a greater distance are at risk of infection. The settling time of a spherical particle with a diameter of about 4 μm suspended at a height of 1 m is about 30 minutes. Settling particles with a diameter of 1 μm takes about a few hours. Molecules smaller than 10 μm (infectious) are dangerous to human health as they penetrate deep into the lower respiratory tract. Therefore, it should be clearly stressed that the size of individual virus molecules (coronavirus size) is crucial for epidemiology. Small amounts of viruses do not cause disease in healthy people. At higher concentrations, the risk of infection in humans increases rapidly. The characteristics of the virus in terms of particle size and concentration are crucial in the prevention and protection against viral infections [10].

II. Analysis of acoustic wave interactions with heterogeneous fluid

The heterogeneous fluid analyzed at work is the polluted air, that is, the fluid where fine particles of impurities (viruses) are suspended. The interaction of acoustic waves with an inhomogeneous fluid is a physical phenomenon that accompanies the propagation of these waves in aerosols and suspensions. The scientific description of these phenomena is called diffuse phase acoustics, that is, the acoustics of only one component of a two-component, in which the acoustic wave spreads. The physical phenomena analyzed are related to the transfer of momentum from the dissipation fluid where the acoustic wave spreads to the particles suspended in it. This leads to acceleration of particle movement, to changes in local particle concentration [11]. Accelerating the movement of dispersed particles in fluid has important application aspects. During acoustic processes, the rays of diffuse particles are increased and therefore the toxicity of the aerosol decreases. Increasing the radius and weight of particles may also cause their precipitation from the medium under the influence of gravity.

Both, in theoretical and experimental works the authors emphasize that an important issue is the selection of such values of acoustic wave parameters to the parameters of particles suspended in the air so that the processes of increasing particle size are optimal [12].

Particles of a solid or liquid dispersed in air are highly mobile. If an acoustic wave propagates in the air, the scattered particles additionally show more complex motions: they take part in the motion of the vibrating medium and move in a translational way, i.e. they are lifted, drift under the influence of factors such as, inter alia, the pressure of sound radiation per particle and the asymmetry of the motion of the vibrating medium in a standing wave [13].

In an acoustic field, the actual motion of a particle suspended in air is composed of a rapid oscillating motion and a slow translational motion with respect to a fluid medium. The progressive component of this movement is called drift. As a result of the vibrating motion of particles resulting from the propagation of the acoustic wave, coagulation occurs, i.e. the merging of the dispersed particles into larger units (aggregates). Oversized particles lose their toxicity because the human respiratory system has the ability to keep particles larger than a few micrometers out of the lungs. After reaching the appropriate size, the particles also lose their ability to stay in the air and fall, sink down (sedimentation) [14].

III. Comparative analysis of radiation and asymmetric drifts

Acceleration of the movement of particles in the fluid under the influence of an acoustic wave

Physical phenomena such as radiation pressure and the asymmetry of oscillating motion help to coagulate the particles by accelerating their motion in the acoustic field of the traveling wave and collecting them in arrows or in the nodes of the standing wave, where they combine into larger aggregates [15].

In order to compare different types of drifts and characterize their dependence on parameters: air, acoustic wave and suspended particles, the values and directions of forces acting on these particles must be specified. The appropriate expression for the radiation force drift is follows [11]:

$$F_{DR} = \frac{8}{3}\pi k r_p^3 \mu_g^2 \bar{E} \sin 2kx$$

(1)

where:

k – number of wave, r_p – radius of the particle, μ_g – the flow-around coefficient.

This coefficient takes the following form [11]:

$$\mu_g = \frac{\omega\tau}{\sqrt{1+\omega^2\tau^2}} = \sin\varphi$$

(2)

Where ω – angular frequency, φ – phase shift angle, τ – the relaxation time,

$$\tau = \frac{m_p}{6\pi\eta r_p}$$

(3)

η – kinematic viscosity of the gas.

The mean energy density of the wave is equal [11]:

$$\bar{E} = \frac{1}{2}\rho_g U_g^2$$

(4)

where:

U_g – gas velocity amplitude.

The symmetric force drift is follows [11]:

$$F_{DA} = -\frac{2}{3}\pi k r_p^3 \frac{\rho_p}{\rho_g}\bar{E}\mu_p^2 sin2kx$$

(5)

where: ρ_g – density of the gas, ρ_p – density of the particle, μ_p – the entertainment coefficient of the particle. This coefficient takes the following form [11]:

$$\mu_p = \frac{1}{\sqrt{1+\omega^2\tau^2}} = \cos\varphi$$

(6)

The acceleration under the influence of drift forces should be determined. The figure A_D is introduced that is the ratio of the maximum value of the drift force to the mass of the dispersed phase particle [11,3].

The forces exerted on the scattered particle depend on its position in relation to the nodes and arrows of the standing wave; regardless of the considered mechanism of the phenomenon, the values of the drift force F_D are described:

$$F_D(x) = F_0 \sin 2kx$$

(7)

where: F_0 is the amplitude of the drift force $F_0 = (F_D)_{max}$.

For $F_0 > 0$, as in the case of R-type drift for particles in the air, they are directed to the arrows of the standing wave, which is easy to see by evaluating the drift force potential:

$$U_D(x) = (2k)^{-1}F_0 \cos 2kx$$

(8)

For $F_0 > 0$, the points of permanent equilibrium are defined by $cos2kx = -1$, which is the equation of the planes of arrows. However, for $F_0 < 0$, the particles are collected in the nodes of the standing wave.

In the further discussion, the sign of the drift force is not considered, as the acceleration values of particles under the influence of drift forces of different types will be compared.

Assessment of the acceleration value of particles in the air under the influence of drift forces in the field of an acoustic standing wave

The calculation of the AD value having the acceleration dimension enables the comparison of the effectiveness of the various types of drift. This allows for the assessment of the contribution of earth acceleration to the movement of particles, which is important when considering drift in the acoustic field and falling particles in the gravitational field.

Assuming a spherical particle shape, with a mass of m_p:

$$m_p = \frac{4}{3}\pi r_p^3 \rho_p$$

(9)

particle accelerations under the influence of drift forces for different types of drift can be expressed as follows:

- radiation drift

$$A_{DR} = 2k\rho_p^{-1}\mu_g^2\bar{E}$$

(10)

- asymmetric drift

$$A_{DA} = -\frac{1}{2}\rho_g^{-1}k\mu_p^2\bar{E}$$

(11)

The A_{DA}, A_{DR}, values depend on the particle radius and the nature of the drift (the second lower index indicates the drift type). Figure 1. shows the values of particle acceleration under the influence of drift forces in the standing wave field for the following selected parameters of acoustic wave, medium (air) and scattered particles (viruses). The acceleration of gravity (dashed line) causes particle sedimentation [16].

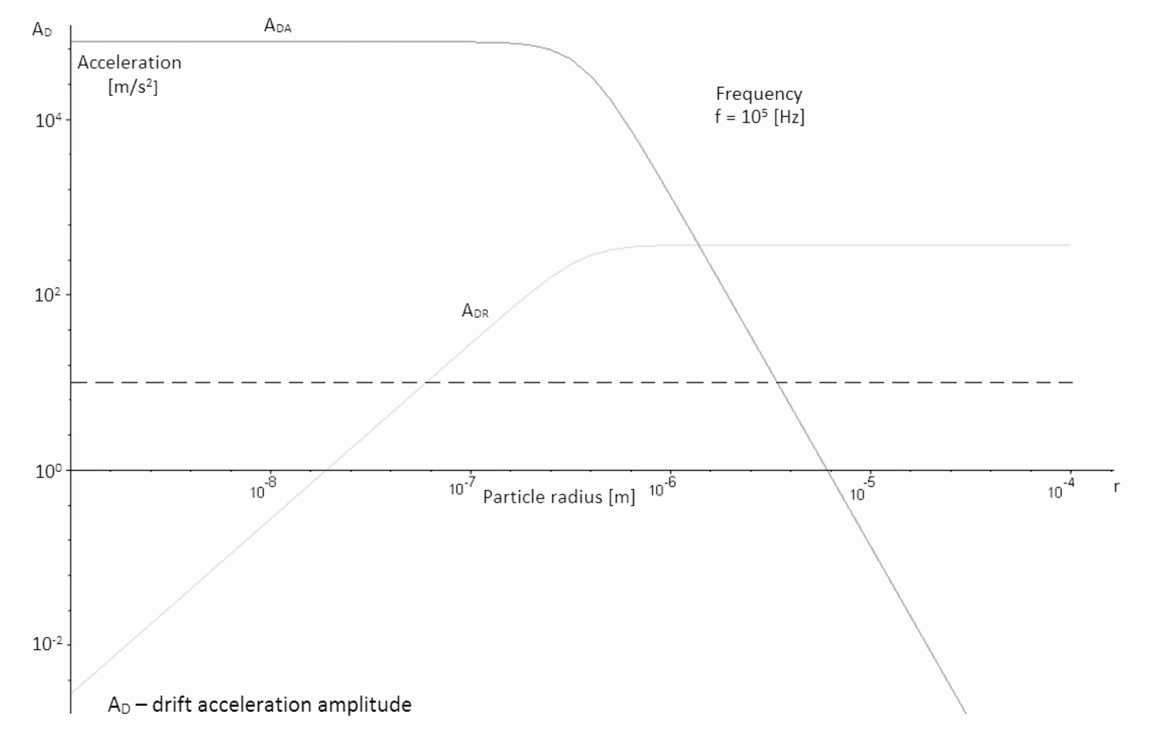

Fig. 1. Drift acceleration amplitudes A_{DA} and A_{DR} compared to the acceleration of gravity.

The types of drift dominate in various ranges of particle radius variation. For the largest particles (droplets), with radius of 10^{-4} - 10^{-5} [m], the R type drift dominates, the smallest particles with radius of $r < 10^{-6}$ [m] will move under the influence of A-type drift.

Graph of particle accelerations under the influence of drift forces of various types, as a function of the particle radius, made for one wave frequency f (Fig. 1) also confirm this conclusion.

The analysis and comparison of the formulas defining the acceleration of the drift force that affect the particles in the air shows that:

• for a given particle size r = const., which is the case for monodisperse suspensions, the type of drift is determined by the wave frequency. The critical frequency of the acoustic wave can be determined, defining the domination areas of both types of drift: radiative and asymmetric.

• at a given frequency of the acoustic wave f = const., a critical value of the particle radius can be determined, which determines the area of domination of both considered types of drift.

IV. Conclusions

Aerosols particles (viruses) floating in the atmosphere, pose a threat to human health, they are the cause of many diseases. Harmful aerosols have an impact on microorganisms, plants and especially living organisms. They introduce the aerosols through the respiratory system inwards.

The method presented to reduce the toxicity of polluted air is not universal. However, it can be used in hospital premises, health care facilities, gymnasiums, airplanes, trains, where large groups of people move and the concentration of viruses can be significant.

The analysis carried out entitles one to conclude that acoustic wave parameters can be selected for the parameters of particles dispersed in the air so that the coagulation effect of particles and increasing its size is optimal.

The considerations show that particles as small as airborne viruses can be effectively accelerated (type A drift) and they can coagulate into larger aggregates in the acoustic standing wave field.

The analyzed in this paper problems requires further theoretical and experimental studies considering usability in the protection of human health.

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