THE ABSORPTION OF ULTRASOUND IN A FLUID BY SMALL OBSTACLES OF SPHERICAL FORM

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The presented study involves the problem of acoustic energy absorbed by aerosols. The aim of this paper is to present results of the valuation of ultrasound energy absorption general coefficient in the dispersions (aerosols). Aerosol particle is an obstacle for acoustic wave propagating and to surmount of which some energy of the medium vibrating is lost. Aerosol particle results in both acoustic energy scattering and its absorption. Besides, there are heat losses connected with periodic variation of the medium temperature. In this connection propagation of acoustic wave in the aerosol is related to decrease in wave intensity to more extent than in propagating a wave in a pure gaseous medium.

INTRODUCTION

The problem of the interaction of ultrasonic waves with aerosols is interesting by itself as one of fundamental physical effects of ultrasound. The subject area contains important aspects of the natural environment protection. This problem has been studied in connection with technical application for precipitation of fluid [1], [2], [8]. In this work considerations involve acoustic field at isotropic and homogeneous medium where inclusions of acoustic- propertied material are suspended varying from the medium properties, such as air suspended dust (aerosols). Presence of inclusions in the medium contribute to propagation of acoustic wave; mean density and compressibility of the medium change and there follows dissipation of incident wave and its damping. Besides, there are heat losses connected with periodic changes of the medium temperature.

Acoustic wave scattering theory on spherical and cylindrical obstacles was presented by Rayleigh [6] next developed by Lifszic [4]. Acoustic wave absorption general coefficient in the aerosols is equal to the sum, Mednikov [5]:

$$\alpha_p = \alpha_p^s + \alpha_p^v + \alpha_p^\chi \tag{1}$$

where:

α_p^s - acoustic energy scattering coefficient in the aerosols

α_p^v - acoustic energy absorption coefficient

α_p^χ - acoustic energy absorption coefficient conditioned by periodic heat flow from a particle to the medium and inversely, and by increase in the medium entropy.

Values of acoustic energy scattering and absorption coefficients in the aerosols have been estimated for parameters of aerosol particles and acoustic field, in view-point of practical applications interest.

1. ESTIMATION OF ACOUSTIC ENERGY SCATTERING COEFFICIENT IN THE AEROSOLS

Loss of energy flux of acoustic wave *J* passing through aerosol layer in *dx* thick can be determined by:

$$\frac{dJ_s}{J} = \alpha_p^s dx \tag{2}$$

Acoustic energy scattering coefficient in the aerosol depends on parameters of aerosol particles and acoustic field [5]:

$$\alpha_p^s = \frac{28}{3}\left(\frac{\pi f}{c}\right)^4 \mu_g^2 \frac{r^3}{\rho_p} k \tag{3}$$

where; f – wave frequency, c - acoustic wave velocity in air, r – particle radius, ρ_p – particle density, k – particle weight concentration, μ_g – flow around coefficient.

For the quantitative analysis of described effects it is being assumed following numerals parameters values which characterize acoustic field, aerosol particle and the medium:

particle density: $\rho_p = 10^3$ [kg/m^3] ,
medium density $\rho_g = 1{,}2$ [kg/m^3] ,
acoustic wave velocity in air: $c = 340$ [m/s],
rang of particles radius: $r = 10^{-7} - 10^{-4}$ [m],
wave frequency: $f = 20 – 50$ [kHz] ,
particle weight concentration $k = 10^{-3}$ [kg/m^3].

Acoustic energy scattering coefficient in the aerosol (3) calculated for dust particles in the air is of low value, of the order of $\alpha_p^s \approx 10^{-20}$, thus it may be neglected at practical problems.

Therefore acoustic wave absorption general coefficient in the aerosols is equal to the sum:

$$\alpha_p = \alpha_p^s + \alpha_p^v + \alpha_p^\chi \approx \alpha_p^v + \alpha_p^\chi \tag{4}$$

2. VALUES OF ACOUSTIC ENERGY ABSORPTION COEFFICIENT IN THE AEROSOLS

Theory of acoustic energy absorption through immoveable obstacles of spherical and cylindrical shape was the first time presented by Sewell [7]. Acoustic energy being absorbed while a particle of aerosol is flowing round through a viscous medium is numerically equal to work of resisting forces set by a particle of medium motion. In case of absorption, loss of energy is defined by:

$$\frac{dJ_a}{J} = \alpha_p^v dx \tag{5}$$

where:

dx stands for thickness of aerosol layer through which acoustic wave passes.

Coefficient of acoustic energy absorption spherical particles is in the form of:

$$\alpha_p^v = \frac{9}{2}\frac{\nu k}{c\rho_p r^2}\mu_g^2\left(1 + r\sqrt{\frac{\omega}{2\nu}}\right) \tag{6}$$

where:

ν - kinematical viscosity of the gas, ω - angular frequency.

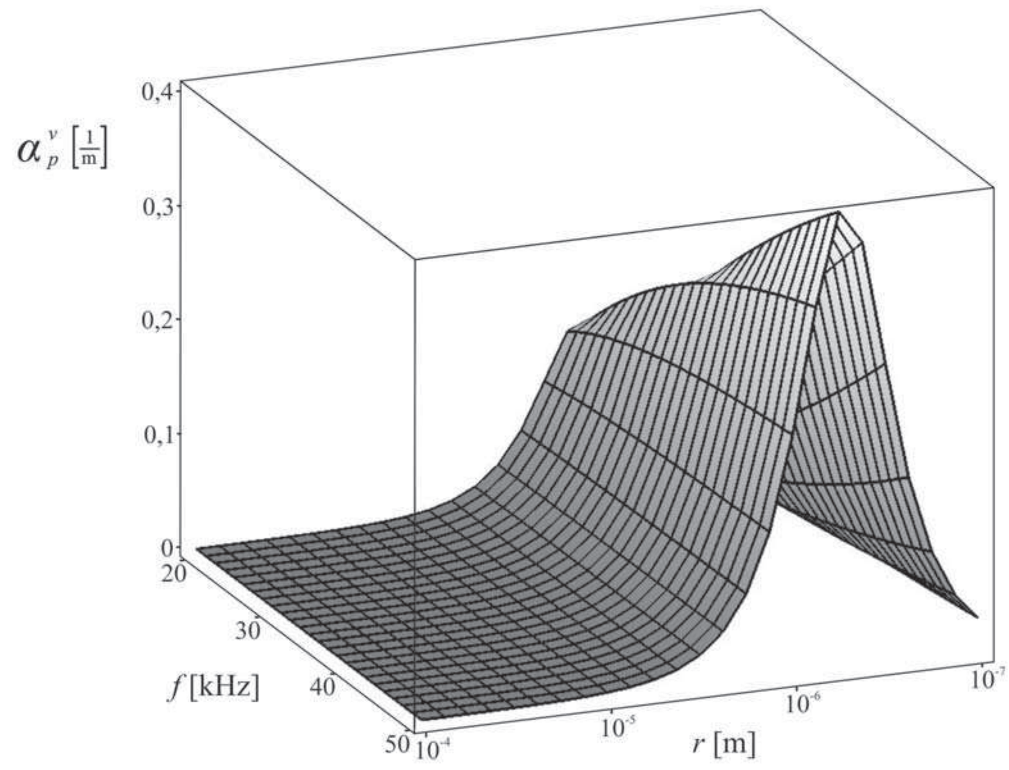

Fig.1. Coefficient of acoustic energy absorption α_p^v *(r, f)* as function particle radius and wave frequency

In coagulation practice (r - high values match ω - low values), the second constituent within the bracket is much smaller than unit, thus it may be neglected. Then for acoustic energy absorption coefficient an expression is obtained:

$$\alpha_p^v = \frac{9}{2}\frac{\nu k}{c\rho_p r^2}\mu_g^2 \tag{7}$$

Equating a derivative to zero:

$$\frac{d\alpha_p^v}{dr} = 0 \tag{8}$$

critical value of a particle radius can be determined for which acoustic energy absorption coefficient is maximum:

$$r_{kryt} = \left(\frac{9\eta}{4\pi\rho_p f}\right)^{\frac{1}{2}} \tag{9}$$

and maximum value of acoustic energy absorption coefficient for critical value of a particle radius:

$$(\alpha_p^v)_{\max} = \frac{\pi\nu k f}{c\eta} \tag{10}$$

where: η - dynamical viscosity.

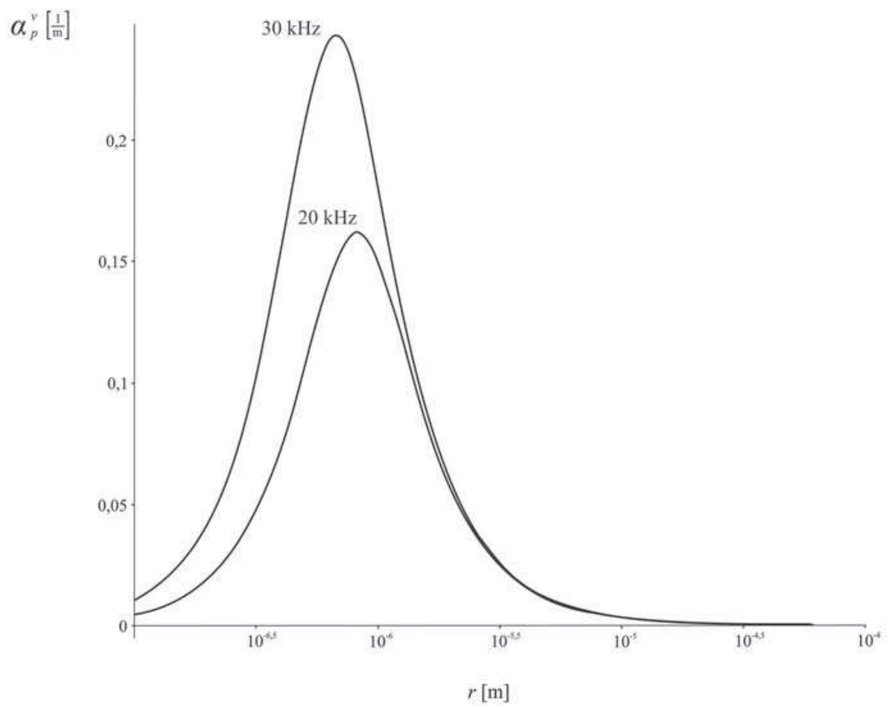

Fig.2. Coefficient of acoustic energy absorption α_p^v *(r,)* as function particle radius for *f = 20 kHz* compared to α_p^v *(r,)* for *f = 30 kHz*.

The formula above has considered that for critical value of a particle radius flow round coefficient $\mu_g = \frac{\sqrt{2}}{2}$.

For this reason it follows that at the given k, concentration of aerosol particles $(\alpha_p^v)_{\max}$ value depends on wave frequency.

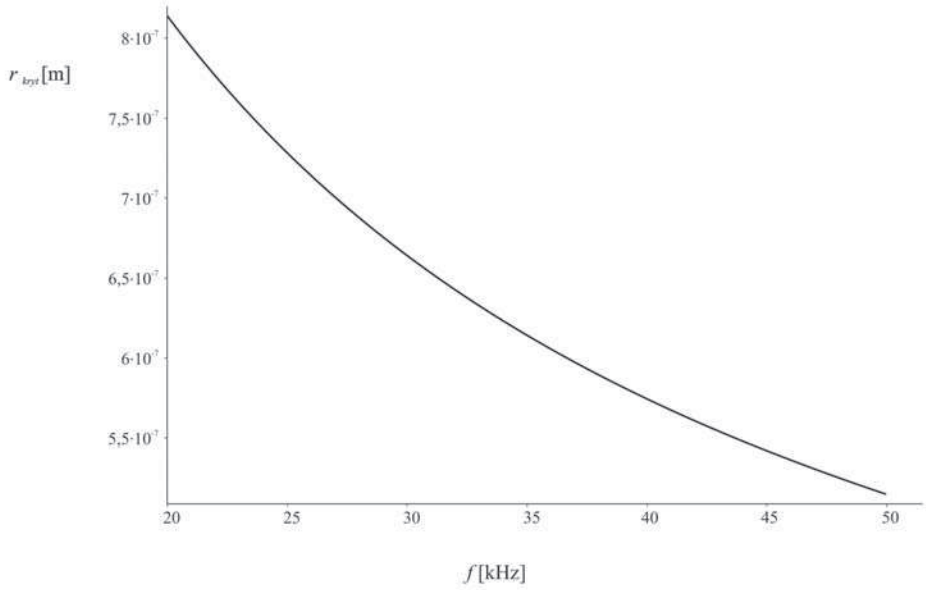

Fig.3. Critical value of a particle radius r_{kryt} *(f)* as function wave frequency

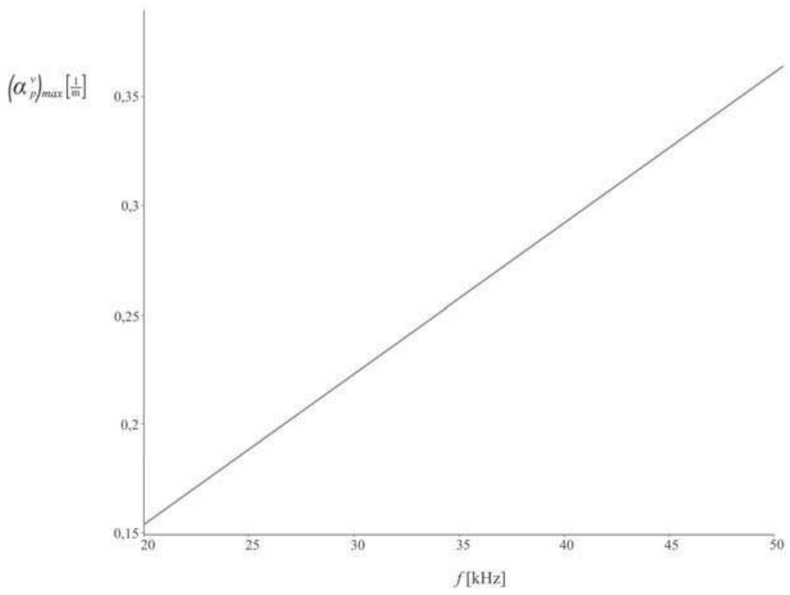

Fig.4. Maximum value of acoustic energy absorption coefficient for critical value of a particle radius $(\alpha_p^v)_{\max}(f)$ as function wave frequency

Acoustic energy particle absorption coefficient – to - maximum value of this coefficient ratio is defined by the dependence below:

$$\frac{\alpha_p^{\nu}}{(\alpha_p^{\nu})_{\max}} = \frac{2r_{kryt}^2}{r^2}\mu_g^2 = \frac{9\eta}{\rho_p r^2 \omega}\mu_g^2 \tag{11}$$

From the formula (9) it is possible to determine critical value of wave frequency depending on radius value of aerosol particle:

$$f_{kryt} = \frac{9}{4}\frac{\eta}{\pi\rho_p r^2} \tag{12}$$

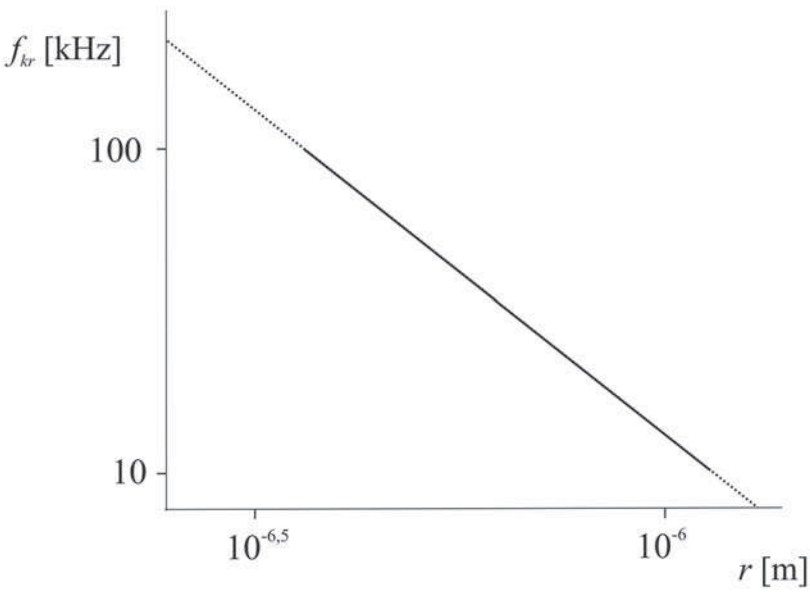

Fig.5. Critical value of wave frequency as function radius value of aerosol particle

3. VALUES OF ACOUSTIC ENERGY ABSORPTION COEFFICIENT ARISING FROM PERIODIC VARIATION OF THE MEDIUM TEMPERATURE

Acoustic wave absorption coefficient conditioned by periodic heat flow from a particle to the medium and inversely and by increase in the medium entropy and at the same time by loss of free energy is defined by expression Epstein and Karhart [3]:

$$\alpha_p^{\chi} = \frac{3\chi k \cdot 10^{-3}}{c\rho_p r^3}(\kappa - 1)\mu_{g\chi}^2 \tag{13}$$

where; χ - temperature coefficient of conductivity, κ -adiabatic exponent, $\mu_{g\chi}$ - degree of the medium and particle temperatures leveling determined by analogous expression as particle flow round coefficient:

$$\mu^2{}_{g\chi} = \frac{a^2}{a^2 + 3a\theta + \frac{9}{2}\theta^2 + \frac{9}{2}\theta^3 + \frac{9}{4}\theta^4} \tag{14}$$

symbols:

$$a = \frac{2}{3}\frac{m_p}{m_g} + \frac{1}{3} \approx \frac{2}{3}\frac{\rho_p}{\rho_g} \quad \text{and} \quad \theta = \frac{1}{r}\sqrt{\frac{2\chi}{\omega}} \tag{15}$$

where:

m_p - mass of particles, m_g – mass of medium, ρ_g – medium density.

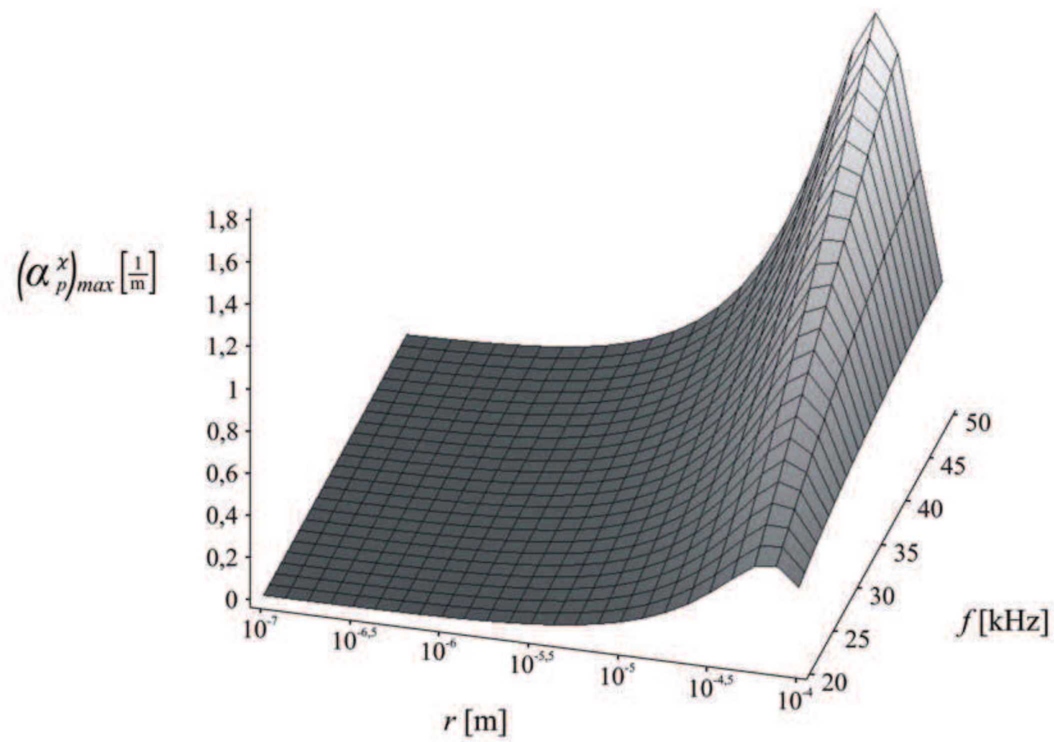

Fig.6. Acoustic energy absorption coefficient arising from periodic variation of the medium temperature α_p^χ *(r,f)* as function particle radius and wave frequency

4. CONCLUSIONS

Results of calculations allow to express conclusions:

- Acoustic energy scattering coefficient in the aerosols (dust particles in the air) is of very low value, and so it may be omitted in practical problems.
- Acoustic wave absorption coefficient in the aerosols is dependent on value of a particle radius, acoustic wave frequency. Value of this coefficient is proportional to particle concentration.

- There is critical value of a particle radius for which acoustic energy absorption is maximum.
- Maximum value of acoustic energy absorption coefficient can be determined for critical value of a particle radius.
- At the given k – concentration of aerosol particles, $\alpha_p^v -$ value depends on the wave frequency.
- There is critical value of wave frequency which depends on value of aerosol particle radius.
- Even at not high critical radius value aerosol particle concentration, α_p^v - absorption coefficient is able to reach high values compared with absorption coefficient at the pure gaseous medium.
- α_p^v - value can be reduced by changing the wave frequency so that it will be different from critical frequency (12).
- For high θ - values the medium – and- particle temperatures are nearly equal, reduction of free energy is insignificant and three fore $\mu_{g\chi} \approx 0$. For low θ - values particle temperature remains almost unchanged, loss of free energy reaches maximum value, $\mu_{g\chi} \approx 1$.

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