ACOUSTIC FIELD INFLUENCE ON KINETICS OF PHASE TRANSITION: WATER - STEAM

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In the work under presentation it was performed theoretical analysis of acoustic field influence on processes proceeding into two-component medium which is fog (waterdrops suspended in the air). Acoustic waves may influence on media where they propagate.Acoustic field, except for the fact that causes to accelerate waterdrop coagulation process, influences kinetics of phase changes: water – steam (gas). If gas medium is not steam – saturated enough then under acoustic field, evaporation of waterdrops suspended in the air follows. If then gas medium is steam – saturated enough so under acoustic field increase in size of waterdrops follows (fog condensation). In the both cases the change of waterdrop radius value is observed, suspended in the gas medium and this causes the change of its clarity. Under specific conditions these processes cause fog dispersal, then it is possible to use acoustic field as agent causing increase in atmosphere clarity.

INTRODUCTION

The problem under presentation include fields of science wide apart - requires to study: hydroacoustics, thermodynamics, mathematics. Studies in this field cause special trouble because the problems connected with the issue is very complicated and the objects under investigation have not large sizes and are extremely active.

Two – component medium which is fog arises when in the humid air very small waterdrops are formed with the diameter less than $5 \cdot 10^{-5}$ [m]. The more humid air the bigger probability for fog to arise. The second essential factor referring to the formation of fog is temperature; the lower one the less steam is in the air.

Evaporation process consists of two elementary processes:

- detaching molecules from liquid face
- molecules diffusion to surrounding medium.

After Maxwell [7], waterdrop evaporation rate in the stationary medium is described by:

$$J_f = 4\pi Dr(c_H - c_\infty) \tag{1}$$

where:
D - is steam diffusion coefficient
c_H – is saturated steam concentration
c_∞ - is saturated steam concentration in surrounding medium

Assuming that fog makes definite system of waterdrops and that each of them is in vessel with radius equal *b* it is possible to determine fogdrop evaporation rate in stationary medium [7] as:

$$J_f \approx 4\pi Drc_H \exp\left[-\frac{3rD}{(b-r)^3}t\right] \tag{2}$$

where: t – is time.
In the moving medium speed of evaporation increases several times:

$$m = 1 + \beta(Sc)^{\frac{1}{3}}(\mathrm{Re})^{\frac{1}{2}} \tag{3}$$

where:
m – is called multiplier, while
β - is certain constant equal approximately 0,276,
$Sc = \frac{\nu}{D}$, is Schmidt number equal approximately for steam in the air under standard conditions 0,7,
ν – is coefficient kinematic viscosity, while
$\mathrm{Re} = \frac{2ru_{gp}}{\nu}$ is Reynolds number which determines inertial force ratio to force of internal friction, where u_{gp} is value of relative medium motion velocity. Reynolds number is criterion to determine characteristic of all incompressible fluid flow.

In this case, speed of drop evaporation defines Fressling equation:

$$J_f = 4\pi D(c_H - c_\infty)\left(1 + K\sqrt{\mathrm{Re}}\right) \tag{4}$$

where: K determination is taken:

$$K = \beta(Sc)^{\frac{1}{3}} \tag{5}$$

From the equation it follows that speed of waterdrop evaporation increases including increase in Reynolds number from Re =1. It appears from here that:

$$u_{kp} = \frac{\nu}{2r} \tag{6}$$

where:

u_{kp} - is critical value of relative medium motion velocity. This value depends on dispersion of waterdrops. Specific quality of gas medium vibration under acoustic wave is reaching large speed value compared to speed of other small molecules suspended in the medium [4].

After Fuks [5], waterdrop evaporation in nonstationary conditions can be treated as quasistationary process with small values of drop radius.

Equations (3) and (4) are right as well with the presence of vibration medium provided that vibration amplitude is large compared to drop radius, that is $A_g >> r$.

1. ASSESSMENT OF ACOUSTIC FIELD INFLUENCE ON PHASE TRANSITION WATER – STEAM

Acoustic field influences kinetics of phase transition water – steam (accelerates process) when relative velocity of medium vibration is higher than given with the formula (6). During the process of evaporation drop radius decreases after the following formula:

$$r = \sqrt{const \cdot \frac{D}{f} + \left(r_0^2 - const \cdot \frac{D}{f} \right) \exp\left(\frac{f c_H}{\rho_p} t \right)} \tag{7}$$

where:
r_0 – is initial drop radius
f – wave frequency

When, during evaporation, drop radius value decreases then at the same time speed of drop flow round diminishes and next this causes to decrease Reynolds number. Then it follows that acoustic field does not speed up the process of evaporation while Reynolds number diminishes, that is when Re < 1.

One should notice that simultaneously with the process of evaporation coagulation of drops in acoustic field follows, that is to say enlargement of their sizes [4]. As it appears from our early considerations [4] coagulation of waterdrops follows with sufficient large weight concentration of waterdrops in gas medium.

Numerical concentration of waterdrops is described by formula:

$$n = \frac{\kappa \cdot 10^{-9}}{\frac{4}{3}\pi r^3 \rho_p} \approx 0{,}24 \cdot 10^{-9} \frac{\kappa}{r^3 \rho_p} \tag{8}$$

where:
κ – is weight concentration of waterdrops
ρ_p – is particle density.

Summary amount of water evaporated from all drops is, on regarding (8) and (4):

$$G_f = Jn \cdot 10^3 = \frac{3kD}{\rho_P r^2} \left(c_H - c\infty \right) \left(1 + K\sqrt{\mathrm{Re}} \right) \tag{9}$$

From the formula (9) one can see dependence of summary amount of water evaporated on waterdrop radius G (r) that is on dispersion of drops: the bigger waterdrop radius the smaller G value with equal weight concentration of waterdrops and in meeting conditions:
$\mathrm{Re} \rangle 1$ and $\mu_g \to 1$.

Condensation is phase transition of gas into liquid which is only possible in temperatures smaller than critical temperature. Condensation occurs through down or isothermal gas compression. The process of waterdrop condensation in gas medium [5] is described by the same equations which describe process of evaporation. Then dependences presented above are applied as well in the case of condensation.

Kinetics of phase transitions water – steam is also characterized by heat exchange between waterdrops and gas medium and vice versa. With the value of numbers Re<100 equality is performed [5]:

$$Nu = 2\left(1 + \beta(\mathrm{Pr})^{\frac{1}{3}}(\mathrm{Re})^{\frac{1}{2}}\right) \tag{10}$$

where:
Nu – is Nuseelt number
Pr - is Prandtl number
λ_q - is coefficient of medium thermal conductance.

Nuseelt number and Prandtl number are similarity numbers also called critical ordinals. These are physical dimensionless quantities usually defined as proportion by dimension qualities easy to measure. Their value allow to characterize nature and phenomena described by them. If two systems have the same value of dimensionless number describing specific system that is to say that these systems are dynamically alike.

Nuseelt number expresses speed of heat motion on conduction path. Nuseelt number is defined as:

$$Nu = \frac{\alpha \cdot d}{\lambda_q} \tag{11}$$

where:
α – is convective heat – transfer coefficient,
d – linear dimension,
λ_q – is thermal conductivity

Prandtl number defines formula:

$$\mathrm{Pr} = \frac{c_p \eta}{\lambda_q} = \frac{\nu}{a} \tag{12}$$

where:
c_p – is specific heat
η – is coefficient dynamic viscosity
a – is coefficient of temperature levelling

2. LIGHT DISPERSION THROUGH WATERDROPS IN AIR

The size of waterdrops is usually repeatedly bigger than length of visible light wave, $\lambda = 0.40\ 10^{-6} – 0{,}76\ 10^{-6}$ [m], that is why light dispersion occurs here according to laws of geometric optics. The coefficient of light dispersion through waterdrops in air a depends on droplets gravimetric concentration κ and on their radius r. The coefficient of dispersion a is the bigger the smaller radius of droplet is and the bigger gravimetric concentration is [7]:

$$\alpha = \pi r^2 n = \frac{const \cdot \kappa}{\rho_p r} \tag{13}$$

where:
n – is numerical concentration of droplets, while
ρ_p - is density of droplets.

If $r << \lambda$ then the coefficient of dispersion a is proportional for:

$\frac{\kappa r^3}{\lambda^4}$ (i.e. the other dependence of droplets size).

Flow of light intensity J going through fog diminishes including exponential distance [7]:

$$J = J_0 e^{-kx} \tag{14}$$

where:
J_0 – is initial magnitude of light intensity flow
x – is distance.

The coefficient of light weakening is proportional for the coefficient of light dispersion through waterdrops in air: a.

The clarity of atmosphere obtained by fog precipitation is the bigger:

- the smaller relative coefficient of light dispersion is;

$\frac{\Delta\alpha}{\alpha}$ marked in [%]

- and the bigger relative distance is, at which initial magnitude of light intensity is kept:

$\frac{\Delta x}{x}$ marked in [%]

3. CONCLUSIONS

An air with phase inclusions near to phase transition represents an example of complex media, when at determination of the acoustic characteristics it should take into account phase transformations.

Acoustic field, except for acceleration of waterdrop coagulation process in gas medium [4] also influences kinetics of phase transitions water – steam. According to medium temperature and to quantity of steam in the medium follows acceleration of evaporation process or condensation.

It always causes change of waterdrop radius value. Atmosphere clarity depends on waterdrop radius. Then under specific conditions, with adequate selection on acoustic field parameters to waterdrop dispersion suspended in the air, it is possible to obtain intensification of fog dispersion processes.

The problems under discussion requires further theoretical and experimental studies considering usability in practice.

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