VAPORIZATION OF A DROP IN AN ACOUSTIC FIELD

A. M. Boldarev, A. P. Burdukov,
and V. E. Nakoryakov

Transfer processes are known to be materially accelerated in a high-power acoustic field [1-5]. A detailed analysis of work on the influence of acoustic vibrations on heat and mass transfer was given by Fand and Key [5]. We previously [3] published a solution for mass transfer from solids of simple shape under free-convection conditions.

The transfer under free-convection conditions was calculated for a sphere in an acoustic field. The sphere under consideration was placed in a medium perturbed by an acoustic wave with the following parameters: B was the vibration-rate amplitude, ω was the angular frequency, S was the displacement amplitude, and λ was the acoustic wavelength (Fig. 1). The problem was solved with the following assumptions: a) the acoustic wavelength was far greater than the sphere radius, $\lambda \gg R$; b) the ratio of the displacement amplitude to the sphere radius was either far greater than one, $S/R \gg 1$, or far less than one, $S/R \ll 1$; c) the Grashoff number tended to zero, $G \to 0$.

With this formulation of the problem, we found an expression for the dimensionless local mass-transfer constant (Nusselt number) in the form (D is the diffusion constant)

$$N = 1.89 \frac{B}{\sqrt{\omega D}} \frac{\cos^2 \varphi}{\sqrt{1 + \cos^2 \varphi}} \tag{1}$$

In order to verify the transfer mechanism from a sphere to an acoustic field in a gaseous medium, we conducted experiments on mass transfer in the ethanol-air system.

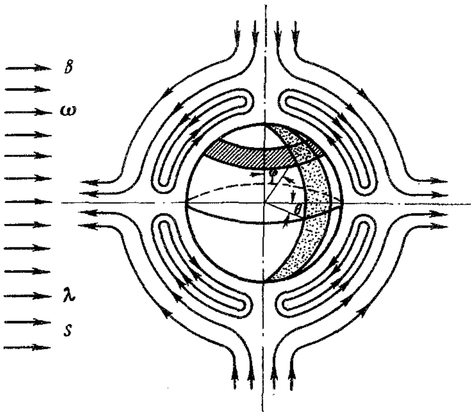

Fig. 1. Acoustic flow around a sphere placed in velocity loop of standing acoustic wave. B) vibration-velocity amplitude; ω) angular frequency; λ) acoustic wavelength; S) displacement amplitude.

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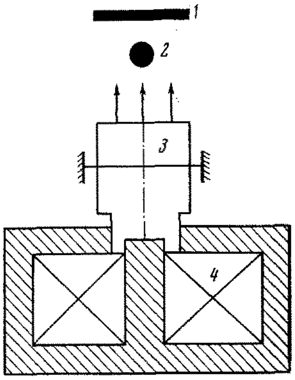

Fig. 2

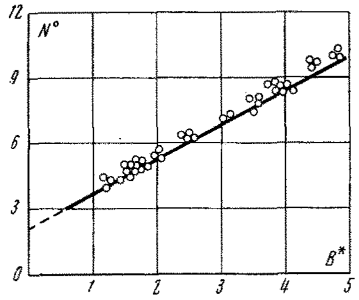

Fig. 3. Mass-transfer constant as a function of acoustic-field parameters. —) Theoretical curve; ○) experimental points.

Drop vaporization was simulated by vaporization of a liquid from the surface of a porous sphere. The experimental setup is shown in Fig. 2, where 1 is the deflector, 2 the porous sphere, 3 the acoustic radiator, and 4 the electromagnet.

The acoustic-wave source was an electrodynamic emitter, which made it possible to obtain sound of sufficiently high intensity (up to 165 dB). In contrast to high-power emitters operating in air, which usually generate highly irregular sound, this radiator made it possible to obtain acoustic vibrations with a uniform amplitude along the wave front. A detailed description of this type of emitter was given earlier [3].

The mass transfer from the sphere was investigated in a stationary acoustic field. The strength of the acoustic vibrations was measured with a piezoelectric pressure sensor having a cylindrical sensing element with an inside diameter of the order of 1.5 mm. The frequency of the acoustic vibrations was measured with a frequency meter. The amount of liquid vaporized from the sphere surface was measured by the volumetric method. Ethanol was used as the working fluid.

The experimental method was as follows: a standing acoustic wave was set up, and the sphere introduced into a velocity loop. The working liquid was forced through the sphere, a definite vaporization regime was established by adjusting the pressure in the working-liquid delivery system, and the pressure in the channel and the strength of the acoustic vibrations were held constant throughout the experiment.

The following quantities were measured in each series of experiments: 1) the amount of liquid vaporized from the sphere; 2) the temperature of the sphere surface (with a nichrome-constantan thermocouple contact-welded to the sphere surface); 3) the ambient temperature; 4) the pressure in the acoustic wave; 5) the frequency of the acoustic vibrations.

In this experimental investigation, we determined the dimensionless mass-transfer constant (averaged over the sphere) as a function of the amplitude of the vibration velocity and the frequency of the acoustic vibrations. The acoustic-vibration intensity varied from 150 to 165 dB, and the vibration frequency from 7 to 18 kHz.

The experimental data were processed with Eq. (1). In order to determine the average mass-transfer constant N, it is necessary to average the above theoretical function in Eq. (1) over the sphere, using the formula

$$\langle N\rangle = \frac{1}{F}\int_F N^0 dF$$

where F is the surface area of the sphere and N^0 is the local Nusselt number.

The averaging integral selected numerically in our previous study [3] would produce an error in this case. We can select the exact integral

$$\langle N\rangle = \int_0^{2\pi}\int_0^{\pi/2} N^0 R^2 \cos\varphi \, d\theta \, d\varphi = 1.9\frac{B}{\sqrt{\omega D}}\int_0^{\pi/2}\frac{\sin\varphi\cos^2\varphi}{\sqrt{1-\cos^4\varphi}}d\varphi = 0.95\frac{B}{\sqrt{\omega D}}\left(\sqrt{1-\cos^2\varphi}\right)\Big|_0^{\pi/2} = 1.9\frac{B}{\sqrt{\omega D}}. \tag{2}$$

The dimensionless mass-transfer constant was determined from the well-known formula

$$N = \beta d / D \tag{3}$$

where β is the mass-transfer constant, which is related to the mass flow by the equation

$$q = \frac{\beta M}{R_0 T}(p_\omega - p_\infty)$$

Knowing the saturated vapor pressure at the sphere surface P_ω, the saturated vapor pressure at infinity P_∞, the diffusion constant of ethanol at a temperature T, and the molecular weight of the alcohol vapor M, we can unambiguously define the left side of Eq. (3).

The results of our experimental study are presented in Fig. 3, where $B^* = B(\omega D)^{-1/2}$. As can be seen from this graph, the experimental data are in satisfactory agreement with the theoretical function in Eq. (2).

It must be noted that the theoretical function in Eq. (2) differs from that given by Borisov and Statnikov [4] only in the coefficient.

LITERATURE CITED

1. W. R. Penney and T. B. Jefferson, "Heat transfer from a vibrating horizontal wire to water and ethylene glycol," Heat Transfer, No. 4, ASME Proceedings [Russian translation], Series C, Mir, Moscow (1966), p. 21.
2. P. D. Richardson, "Correlation of experimental data obtained by Fand and Key on the effect of acoustic vibrations on heat transfer," Heat Transfer, No. 2, ASME Proceedings [Russian translation], Series C, Mir, Moscow (1965), p. 183.
3. A. P. Burdukov and V. E. Nakoryakov, "Mass transfer in an acoustic field," Zh. Prikl. Mekh. i Tekh. Fiz., No. 2 (1965).
4. Yu. Ya. Borisov and Yu. G. Statnikov, "Influence of sound on heat and mass transfer processes in gaseous media," Inzh.-Fiz. Zh., 13, No. 3 (1967).
5. R. M. Fand and Key, "Action of acoustic vibrations on free convection near a horizontal cylinder," Heat Transfer, No. 2, ASME Proceedings [Russian translation], Series C, Mir, Moscow (1961), p. 36.