In this way, a comparative analysis of the given experiment for samples from electrolytic and carbonyl nickel powders shows that adsorption layers on the surface of particles of the resulting dispersed layer not only determine the potential barrier of electron emission from the metal [4, 7] but also while passing to the gas phase (desorbing) may by their own pressure separate particles, thereby increasing the same gaps which are barriers for electrons tunneling in the direction of the field.

The results obtained must, obviously, refine the concepts about interparticle contacts and will serve to further the development of the physicomathematical model of transport in a dispersed medium, in particular the one proposed in [8].

LITERATURE CITED

1. G. N. Dul'nev and B. V. Novikov, Inzh.-fiz. Zh., 41, No. 1, 172-184 (1981).
2. M. A. Gol'dshik, Transport Processes in a Granular Layer [in Russian], Novosibirsk (1984).
3. A. Yu. Zubarev, "Effective thermophysical, rheological, and electrophysical properties of several dispersed materials," Dissertation for the degree of Candidate of Physics and Mathematical Science, Sverdlovsk (1968).
4. L. I. Trusov and V. A. Kholmyanskii, Isolated Metallic Films [in Russian], Moscow (1973).
5. R. Khol'm, Electrical Contacts [in Russian], Moscow (1961).
6. S. V. Belov (ed.), Handbook on Porous Permeable Materials [in Russian], Moscow (1987).
7. A. A. Belyaev, Yu. A. Buevich, A. Yu. Zubarev, and V. M. Kiseev, Dokl. Akad. Nauk SSSR, 330, No. 3, 626 (1990).
8. A. A. Belyaev, A. Yu. Zubarev, E. S. Kats, and V. M. Kiseev, Inzh.-fiz. Zh., 55, No. 1, 122-130 (1988).

IMPROVING THE EFFICIENCY OF ACOUSTIC FOAM SUPPRESSION

V. G. Nevolin

UDC 532.501.34:541.182:622.765.066

The loss of efficiency of acoustic foam suppression at higher sound frequencies can be attributed to stabilization of the liquid foam films by high-frequency vibrations.

Tests on the ultrasonic breakdown of flotation foam on copper concentrate have been described previously [1]. We have used the results of these tests to map isographs of the efficiency (degree) of foam suppression by ultrasound at various amplitudes and frequencies (see Fig. 1). The figure indicates that the frequency of ultrasound at a fixed amplitude must be lowered in order to increase the degree of foam suppression. An increase in the frequency, on the other hand, tends to lower the degree of acoustic foam suppression. It seems to us that this effect is attributable to stabilization of the foam by the vibration input.

We now seek to demonstrate this fact. We model the foam by a viscous incompressible fluid layer of infinite extent with free boundaries [2], which corresponds to the case of a coarsely disperse foam, where the characteristic dimensions of the foam films are much greater than their thicknesses. We model the process of acoustic foam suppression as an instability of the plane surfaces of an infinite viscous fluid film of thickness h, which is surrounded by a gas (inviscid fluid) and executes small vibrations along the vertical axis (z-axis) with a frequency ω and an amplitude a ($a \ll 1$) according to the law $a \cos \omega t$.

State Scientific-Research and Design Institute of the Petroleum Industry, Perm. Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 61, No. 3, pp. 373-377, September, 1991. Original article submitted January 3, 1990.

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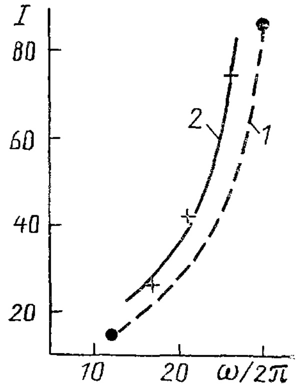

Fig. 1. Isographs of the foam suppression efficiency at various ultrasonic intensities I (mV) and frequencies $\omega/2\pi$ (kHz). 1) 93% suppression; 2) 94% suppression.

This representation corresponds to the case of foam breakdown by sound with a wavelength much greater than the characteristic dimensions of the fluid foam film. Allowing for the fact that the scale of the foam channels does not exceed 1 cm, we obtain an upper limit for the acoustic frequency: The frequency of the acoustic signal must not exceed 34 kHz. The vibration model is then a realistic model of the acoustic breakdown of foam. Foam suppression by this mechanism takes place in the case of small acoustic pressures, i.e., before the onset of shock breakdown.

1. We carry out the analysis in Cartesian coordinates, where the xy plane coincides with the undisturbed upper interface. The lower interface corresponds to the vertical coordinate $z = -h$. The fluid is stationary in a moving coordinate system, and the effective free-fall acceleration is

$$\mathbf{g}(t) = (1 - b\cos\omega t)\,\mathbf{g},\ \mathbf{g} = (0,\ 0,\ -g),\ b \equiv a\omega^2/g \ll 1.$$

Mechanical equilibrium is possible in the given system (liquid–gas) and is described by the equations

$$\mathbf{v}_{0i} = (u_{0i},\ v_{0i},\ w_{0i}) = 0,\ \zeta_{0j} = 0,$$

$$p_1 = \begin{cases} -\rho_1 g(t) z & \text{at } z \geqslant 0, \\ \rho_2 g(t) h - \rho_1 g(t)(h+z) & \text{at } z \leqslant -h, \end{cases}$$
$$p_2 = -\rho_2 g(t) z \quad \text{at} \quad -h \leqslant z \leqslant 0. \tag{1}$$

Here $j = 1$ corresponds to the upper interface, and $j = 2$ corresponds to the lower interface. The fluid labeled $i = 1$ occupies the half-spaces $z \geq 0$ and $z \leq -h$, and the fluid labeled $i = 2$ occupies the layer $-h \leq z \leq 0$.

We consider the stability of the equilibrium (1) in the presence of infinitesimally small perturbations. The system of equations for the perturbations is written in the form [3]

$$\partial \mathbf{v}_1/\partial t = -\beta_1^{-1}\nabla p_1,\ \nabla v_i = 0,\ i = 1,\ 2,\ \partial \mathbf{v}_2/\partial t = -\beta_2^{-1}\nabla p_2 + A^{-1}\nabla^2 \mathbf{v}_2, \tag{2}$$

where $\beta_i \equiv \rho_i/(\rho_1 + \rho_2)$; $A \equiv [\alpha^3/\nu^4 g(\rho_1 + \rho_2)^3]^{1/4}$.

At the interface, assuming that the displacements ζ_j of the surfaces from the equilibrium position are small, we have [3]

at $z = 0$:

$$\partial\zeta_1/\partial t = w_1,\ w_1 = w_2,\ \Delta_1 w_2 = \partial^2 w_2/\partial z^2,$$

$$p_2 - p_1 = [\beta_2 - \beta_1 - \Delta_1 - (\beta_2 - \beta_1)\, b\cos\Omega t]\,\zeta_1 + 2A^{-1}\beta_2 \partial w_2/\partial z; \tag{3}$$

at $z = -H\ (H \equiv h/[\alpha/(\rho_1 + \rho_2)\, g]^{1/2})$:

$$\partial\zeta_2/\partial t = w_2,\ w_1 = w_2,\ \Delta_1 w_2 = \partial^2 w_2/\partial z^2,$$

$$p_1 - p_2 = [\beta_1 - \beta_2 + \Delta_1 - (\beta_1 - \beta_2)\, b \cos \Omega t]\, \zeta_2 - 2A^{-1}\beta_2 \partial w_2/\partial z\,, \tag{4}$$

$$\Delta_1 \equiv \partial^2/\partial x^2 + \partial^2/\partial y^2,\ \Omega \equiv \omega/[g^3(\rho_1+\rho_2)/\alpha]^{1/4},$$
at $|z| \to \infty$:
$$w_1 \to 0. \tag{5}$$

Solving the system of equations (2) subject to conditions (3)-(5) by means of the Laplace transform with respect to time and the Fourier transform with respect to the coordinates x and y and assuming that the viscosity of the fluid is small, we obtain a system of equations for the displacements of the surfaces from the equilibrium position for the case of a dense thin film, when the conditions $kH \ll 1$ and $\rho_1 \ll \rho_2$ (or, equivalently, $\beta_1 \ll 1$, $\beta_2 \approx 1$) hold [4]:

$$d^2\zeta_l/dt^2 + 2\delta d\zeta_l/dt - (d^2\zeta_n/dt^2 + 2\delta d\zeta_n/dt) + [\Omega_{0l}^2 + (-1)^l q \cos \Omega t]\, \zeta_l = 0, \tag{6}$$

where

$$l,\ n = 1,\ 2;\ l \neq n;\ \Omega_{0l}^2 \equiv [k^3 - (-1)^l k]\, kH;\ k^2 \equiv k_x^2 + k_y^2;\ \mathbf{k} = (k_x,\ k_y);\ q \equiv bHk^2;\ \delta \equiv 2k^2/A.$$

Since we are investigating the case in which the characteristic dimensions of the foam channels are not greater than ~1 cm, we find that $k \gg 1$, i.e., $\Omega_{0l}{}^2 = \Omega_0{}^2 \approx k^4H$.

Making a linear transformation of the form

$$\zeta_1 = (\xi_1 + \xi_2)/2,\ \zeta_2 = (\xi_1 - \xi_2)/2,$$

we obtain the equations for ξ_1

$$\xi_1 = (q\xi_2 \cos \Omega t)/\Omega_0^2,\ d^2\xi_2/dt^2 + 2\delta d\xi_2/dt + \\ + (1/2\Omega_0^2)(2\Omega_0^4 - q^2 - q^2 \cos 2\Omega t)\, \xi_2 = 0. \tag{7}$$

This system is a set of Mathieu equations [5]. Solving them for the case of small q, i.e., for $q^2 \ll 2\Omega_0{}^4$, we find that surface waves are excited on the film if

$$b \geqslant b_{*1} = 4(\Omega^3/A)^{1/2}/k_*H = 4\Omega/A^{1/2}H^{3/4}, \tag{8}$$

where the wave number k^* of the most easily excited surface mode is given by the relation

$$\Omega_0^2 \equiv k_*^4 H = \Omega^2. \tag{9}$$

In the case of finite q the surface wave excitation condition is written

$$b \geqslant b_{*2} = 2\Omega^2/Hk_*^2 = 2\Omega/H^{1/2}, \tag{10}$$

since k^* is determined from Eq. (9).

Surface waves are not excited for $b < b_{*1}$ (or for $b < b_{*2}$).

Equations (6) and (7) were derived for the case in which the direction of incidence of the sound wave or the direction of polarization of the vibrations is perpendicular to the liquid foam film. In reality, however, the foam channels have arbitrary orientations. The right-hand sides of Eqs. (6) and (7) acquire driving-force terms when such orientation of the liquid films is taken into account. However, it has been shown [6] that the solution of an inhomogeneous second-order linear differential equation with periodic coefficients and with a periodic function of the same period on the right-hand side is unstable if and only if the solution of the corresponding homogeneous equation is unstable. To simplify matters, therefore, we discuss the homogeneous equation, i.e., the case of perpendicular incidence of sound or perpendicular polarization of the vibrations.

2. The onset of surface waves can lead directly to breakdown of the liquid foam film or accelerated dehydration (thinning) of the film and thus to its eventual breakdown, for example, as a result of van der Waals instability. Taking van der Waals compression (attraction) into account, we can rewrite the expression for the natural frequency of the surface waves in the form [7]

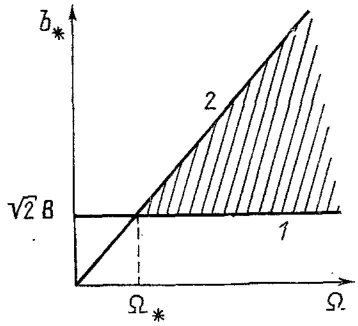

Fig. 2. Stability diagram of liquid foam films (the domain of instability is shown hatched).

$$\Omega_0^2 \to \Omega_0^2 \equiv (k^3 - Bk)\,kH, \tag{11}$$

where $B \equiv (|\partial U/\partial h| - |\partial U_0/\partial h|)/\rho_2 g$, and U and U_0 are the potentials of the van der Waals forces and repulsion of the boundaries.

It follows from Eqs. (7) and (11) that the acoustic excitation (vibrations) responsible for the generation of surface waves induces film breakdown as long as the film is sufficiently thick (so that the van der Waals forces are small), i.e., if $k \gg B^{1/2}$. In the case of thin films, however, i.e., when $k < B^{1/2}$, not only are vibrations (sound) incapable of breaking down the liquid film, they can even have the converse effect of stabilizing it. As a result, foam suppression is negated. This phenomenon is attributable to the dynamic stabilization effect [8, 9].

Indeed, the natural surface wave frequency $\Omega_0{}^2$ changes sign for $k < B^{1/2}$, i.e., for $\Omega_0{}^2 = -Bk^2H(1 - k^2/B) < 0$. Also, it follows from Eq. (7) that the liquid film is stable if $q^2/2\Omega_0{}^2 - \Omega_0{}^2 \geq 0$, i.e., for

$$b \geqslant b_{*3} = 2^{1/2}B + o(1/B). \tag{12}$$

If $b < b_{*3}$, the film breaks down as a result of van der Waals compression.

Thus, the liquid foam film is not broken down if the signal amplitude b satisfies the inequalities

$$b_{*1}\ (\text{or}\ \ b_{*2}) \geqslant b \geqslant b_{*3}. \tag{13}$$

Figure 2 gives a schematic representation of the domains of foam stability and instability. Line 1 corresponds to van der Waals instability, and line 2 to parametric instability of the foam films. Foam suppression takes place if the amplitude of the acoustic (vibration) signal lies below line 1 or above line 2. The foam does not break down if the amplitude of the signal satisfies the relation (13) and the excitation frequency Ω is higher than the critical value Ω* determined from the condition $b_{*1} = b_{*3}$ or $b_{*2} = b_{*3}$, i.e., if it lies in the hatched domain. This clarifies the results of [1], in which the foam suppression efficiency was found to diminish with an increase in the acoustic frequency. This is because the threshold of surface wave excitation (threshold of breakdown of the liquid films) and the attenuation of sound in the interior of the foam increase with an increase in the acoustic frequency. As a result, the amplitude of insonification of liquid films close to the sound source still falls within the domain of instability, and the foam breaks down, but the deeper interior layers of the foam do not break down, because the insonification amplitude lies in the domain of stability of the foam films.

Consequently, in order to improve the efficiency of foam suppression, the intensity of the sound (vibration) input must be increased if the frequency is raised, or in the case of a fixed excitation amplitude the input frequency must be lowered (see Fig. 2) in such a way that the amplitude of the sound wave (vibrations) in the interior of the foam will remain inside the domain of parametric instability.

Here we have discussed only the domain of parametric instability, because it is only practical to insonify a stable foam, i.e., a foam whose film thicknesses do not exceed $2\pi/B^{1/2}$.

NOTATION

α, ν, coefficients of surface tension and kinematic viscosity; ω, Ω, angular and dimensionless modulation frequencies; Ω_0, natural frequency of surface waves; Ω_*, critical vibration frequency; ζ_{0j}, ζ_j, displacements of the j-th surface from equilibrium position; ρ_i, β_i, dimensional and dimensionless densities of i-th fluid; δ, dissipation parameter; ξ_1, ξ_2, amplitude of interface vibrations; a, modulation amplitude; b, q, dimensionless modulation amplitudes; g, free-fall acceleration; x, y, z, Cartesian coordinates; h, H, dimensional and dimensionless thicknesses of liquid film; p_1, p_2, pressures; v_{0i}, $v = (u, v, w)$, fluid velocity vectors; t, time; ∇, gradient operator; i, l, n, indices; j, interface-numbering index; A, analog of Reynolds number; k, wave number, $k = (k_x, k_y)$, wave vector; b_*, critical modulation amplitude; k_*, critical wave number; U_0, U, potentials of repulsive and van der Waals compressive forces.

LITERATURE CITED

1. A. A. Baishulakov, M. N. Sokolov, and Yu. V. Malakhov, Ultrasonic Foam Suppression in Enrichment Plants [in Russian], Moscow (1967).
2. A. Sheludko, Colloidal Chemistry [in Russian], Moscow (1960).
3. L. D. Landau and E. M. Lifshitz, Fluid Mechanics, 2nd ed., Pergamon Press, New York (1987); Theory of Elasticity, Pergamon Press, New York–Oxford (1959).
4. V. G. Nevolin, Zh. Prikl. Mekh. Tekh. Fiz., No. 4, 53-55 (1981).
5. N. W. McLachlan, Theory and Application of Mathieu Functions, Clarendon, Oxford (1947).
6. V. V. Stepanov, Prikl. Mat. Mekh., 14, No. 3, 311-312 (1950).
7. V. G. Nevolin, Zh. Tekh. Fiz., 51, No. 8, 1758-1760 (1981).
8. P. L. Kapitsa, Zh. Éksp. Teor. Fiz., 21, No. 5, 588-594 (1951).
9. V. A. Briskman, Dokl. Akad. Nauk SSSR, 226, No. 5, 1085-1087 (1976).

SURFACE FLOW WITH DISCRETE SINKS

A. V. Shchukin and R. S. Agachev

UDC 621.438:542.46:532.546

Measurements have been made on the coefficient of friction, the pressure, and the turbulence at the surface involving discrete sinks provided by a transverse slot and a hole.

Channel inlet sections are frequently inclined to the surfaces in tangential cooling-air supply to convective film cooling systems for gas turbines (Fig. 1a) or else may be perpendicular to the latter (Fig. 1b). In the first case, the pressure loss in the supply can be calculated from data for the inlet sections of wind tunnels [1] and for aerospace vehicle surfaces [2], but in the second, the scope is more restricted, as there have been only isolated studies in the literature on the overall characteristics [3] or an analysis based on one-dimensional theory [4], where formulas were derived for hole flow coefficients. Pressure coefficients behind holes have been derived [5] and the flows have been visualized when the diameter of such a hole is comparable with the width of the supply channel. Boundary-layer theory applied for vanishing viscosity [6] has given the friction function, but it applies only for distributed porous sinks.

Here we examine flow around a surface having a transverse slot or hole through which the air is partly removed (Fig. 1c). We consider conditions corresponding to inlet channels in gas-turbine cooling systems, where the sink parameter $m_s < 1$.

The experiments were performed with a single slot and single hole, on the assumption that the effects from preceding and subsequent holes or slots would be absent. The channel height H was also taken to be substantially larger than the slot width s for hole diameter d.

A. N. Tupolev Kazan Aviation Institute. Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 61, No. 3, pp. 378-382, September, 1991. Original article submitted October 16, 1990.

0022-0841/91/6103-1074$12.50 © 1992 Plenum Publishing Corporation