cally complex fluids," Prikl. Mekh. Tekh. Fiz., No. 3 (1980).
6. M. A. Matovich and J. R. A. Pearson, "Spinning a molten threadline. Steady-state viscous flows," Ind. Eng. Chem. Fund. 8, No. 3 (1969).
7. S. Kase, "Studies on melt spinning. IV. On the stability of melt spinning," J. Appl. Polymer Sci., 18, No. 11 (1974).
8. M. A. Evgrafov, Asymptotic Estimates and Entire Functions [in Russian], Nauka, Moscow (1979).
9. D. A. Frank-Kamenetskii, Diffusion and Heat Transfer in Chemical Kinetics [in Russian], Nauka, Moscow (1967).

STABILITY OF THE PLANE WAVE FRONT OF FLUID EVAPORATION

E. B. Levchenko and A. L. Chernyakov

UDC 532.70 + 535.211

An evaporation wave is propagated in the bulk of a substance subjected to a powerful radiation flux in a condensed medium. In those cases when the domain thickness in front of the wave front heated because of heat conduction is small compared with the characteristic dimensions of the system under consideration, the realization of a quasistationary regime for which the velocity of wave front motion is determined by the instantaneous value of the energy flux density absorbed in the medium, is generally possible. In fact, the process of material rupture under sufficiently large energy flux intensities (for $Q > 10^5$–10^6 W/cm^2 for metals) is accompanied, as a rule, by different nonstationary phenomena such as self-oscillations in the gas flow, ejection of substance in the form of drops, etc. [1], which apparently indicates instability of the quasistationary evaporation mode.

In this paper the stability of the plane fluid evaporation wave front considered as the surface of discontinuity of the thermodynamic functions of the substance, is investigated. An analogous problem in the theory of slow combustion was investigated by Landau [2], who also discovered the instability mechanism of a plane chemical reaction wave associated with the development of vortical disturbances in the flux of combustion products. In application to the process of substance evaporation by powerful radiation flux, the mentioned instability mechanism turns out to be decisive for the development of fluctuations of a front with wavelengths commensurate to the diameter of the radiation focusing spot. A substantial feature of the evaporation process, because of which results obtained in the theory of slow combustion [2, 3] are not directly applicable to the latter, is the high velocity of vapor escape, which is commensurate with the speed of sound in a gas. Taking account of the vapor compressibility, which is necessary in this case, results in a change in both the conditions of origination and the nature of the development of the instability of the plane fluid evaporation wave front.

Let us select a reference system in which the plane evaporation wave front is at rest, and we direct the Cartesian z axis along the normal to the front so that the domain $z < 0$ is filled with fluid and $z > 0$ with vapor. In this coordinate system the temperature profile is stationary and has the following form in the absence of radiation absorption in the vapor during surface evaporation:

$$T_0(z) = \begin{cases} T_{0l}(z), & z < 0, \\ T_{0g}(z) = \text{const}, & z > 0, \end{cases}$$

$$T_{0l} = T_{0S} \exp\left(\frac{v_l z}{\chi_l}\right) + \frac{Q}{\varkappa_l} \frac{e^{(v_l z/\chi_l)} - e^{\mu z}}{\mu - v_l/\chi_l},$$

where Q is the energy flux density, μ is the coefficient of radiation absorption, $\varkappa_l = \rho_l c_l \chi_l$ is the heat conduction, and c_l, ρ_l is the specific heat and density of the fluid. The surface temperature T_{0S} and the flow velocity v_l are determined from the energy conservation law

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 6, pp. 144-150, November-December, 1982. Original article submitted February 10, 1982.

 0021-8944/82/2306-0870$07.50

$$-\varkappa_l \frac{dT_{0l}}{dz}\bigg|_{z=0} = \rho_l v_l\left(\Delta w_{lg} + \frac{1}{2} v_g^2 - \frac{1}{2} v_l^2\right),$$

where Δw_{lg} is the change in enthalpy during the fluid-vapor phase transition, and the equation for the evaporation rate is

$$v_l = \dot{X}(T_{0S}),\ \dot{X}(T_S) \equiv C_0 e^{-u/T_S},$$

where the preexponential factor $C_0 \simeq$ const equals the speed of sound in the fluid in order of magnitude, and u is the heat of evaporation per atom.

Let us investigate the stability of the plane evaporation wave front with respect to small disturbances for which we linearize the Euler equation (we neglect viscosity) and the heat conduction. Considering the gas motion adiabatic, and the fluid incompressible, we obtain the system of equations

$$z<\zeta: \qquad \frac{\partial v_l'}{\partial t} + v_l \frac{\partial v_l'}{\partial z} = -\frac{1}{\rho_l}\nabla p_l', \quad \operatorname{div} v_l' = 0; \tag{1a}$$

$$\frac{\partial T_l'}{\partial t} + v_l \frac{\partial T_l'}{\partial z} + v_{lz}' \frac{dT_{0l}}{dz} = \chi_l \nabla^2 T_l'; \tag{1b}$$

$$z>\zeta: \qquad \frac{\partial v_g'}{\partial t} + v_g \frac{\partial v_g'}{\partial z} = -\frac{1}{\rho_g}\nabla p_g', \tag{2}$$

$$\frac{\partial \rho_g'}{\partial t} + v_g \frac{\partial \rho_g'}{\partial z} + \rho_g \operatorname{div} v_g' = 0, \quad \frac{\partial S_g'}{\partial t} + v_g \frac{\partial S_g'}{\partial z} = 0,$$

where $\zeta = \zeta(x, t)$ is displacement of the front. The pressure change p_g' of the vapor, which we consider an ideal gas, is related to the density and entropy disturbances by the relationship

$$p_g'/p_g = \gamma \rho_g'/\rho_g + S_g'/c_{Vg}, \quad S_g = c_{Vg} \ln(p_g/\rho_g^\gamma), \tag{3}$$

where $\gamma = c_{pg}/c_{Vg}$ is the adiabatic index, and ρ_g, p_g, S_g are the undisturbed values of the vapor density, pressure, and entropy. The gas temperature is found from the equation of state

$$T_g'/T_g = p_g'/p_g - \rho_g'/\rho_g. \tag{4}$$

The mass, momentum, and energy conservation laws on the wave front for $z = \xi(x, t)$:

$$(\rho_l - \rho_g)\frac{\partial \zeta}{\partial t} = \rho_l v_{lz}' - \rho_g v_{gz}' - \rho_g' v_g; \tag{5}$$

$$(\rho_l v_l - \rho_g v_g)\frac{\partial \zeta}{\partial t} = g\zeta(\rho_l - \rho_g) + p_l' - p_g' + 2\rho_l v_{lz} v_{lz}' - 2\rho_g v_g v_{gz}' - \rho_g' v_g^2 - \alpha \frac{\partial^2 \zeta}{\partial x^2}; \tag{6}$$

$$\begin{aligned}&\left(\rho_l \varepsilon_l + \frac{1}{2}\rho_l v_l^2 - \rho_g \varepsilon_g - \frac{1}{2}\rho_g v_g^2\right)\frac{\partial \zeta}{\partial t} = \rho_l v_{lz}'\left(w_l + \frac{1}{2} v_l^2\right) + \\ &+ \rho_l v_l (v_l v_{lz}' + w_l') - \rho_g v_{gz}'\left(w_g + \frac{1}{2} v_g^2\right) - \rho_g' v_g\left(w_g + \frac{1}{2} v_g^2\right) - \\ &- \rho_g v_g (v_g v_{gz}' + w_g') - \varkappa_l\left(\frac{\partial T_l'}{\partial z} + \zeta \frac{\partial^2 T_{0l}}{\partial z^2}\right);\end{aligned} \tag{7}$$

the condition of equality of the tangential velocity components that follows from the continuity of the tangential components of the momentum flux density

$$v_{lx}' + (v_l - v_g)\frac{\partial \zeta}{\partial x} = v_{gx}', \tag{8}$$

as well as the relationship connecting the velocity of wave front displacement with the change in the fluid evaporation rate

$$\frac{\partial \zeta}{\partial t} = v_{lz}' - \dot{X}', \ \dot{X}' = \frac{v_l u}{T_{0S}^2} T_S' \tag{9}$$

will be the boundary conditions for (1)-(4). The following notation was used in (5)-(9): g is the acceleration of gravity, and $\varepsilon_{l,g}$, $w_{l,g}$ are the internal energy and enthalpy of the fluid and gas.

The change in gas temperature T_g' (z = 0) and fluid surface temperature T_S' are interconnected by the relationship that follows from examining the kinetics of the evaporation process and the gasdynamic regime of vapor escape, which can be written in the general case in the following form

$$\frac{T'_S}{T_{0S}} = a\frac{T'_g}{T_g} + b\frac{\rho'_g}{\rho_g}, \tag{10}$$

where the coefficients a and b should be determined from the solution of the kinetic equation in the transition layer. In the particular case of self-similar escape of vapor, a = 1, b = 0 as is shown in [1].

Utilizing (5), (9) and (10), we reduce the energy equation to the more convenient form

$$\frac{\chi_l}{v_l}\left(\frac{\partial T'_l}{\partial z} + \zeta\frac{d^2T_{0l}}{dz^2}\right) + \xi_0\left(T'_l + \zeta\frac{dT_{0l}}{dz}\right) = \delta_0 T_{0S}\frac{\rho'_g}{\rho_g}, \tag{11}$$

where

$$\xi_0 \equiv \frac{u}{c_l T_{0S}^2}\left(w_g + \frac{3}{2}v_g^2 - w_l - \frac{3}{2}v_l^2\right) + \frac{c_{gp}}{c_l}\frac{T_g}{aT_{0S}} - 1;$$

$$\delta_0 \equiv \frac{b}{a}\frac{c_{pg}}{c_l}\frac{T_g}{T_{0S}} + \frac{v_g^2}{c_l T_{0S}}.$$

We shall seek the solution of (1)-(4) in the form

$$v'_{l,g},\ p'_{l,g},\ \zeta,\ \rho'_g \sim e^{ikx+\Omega t}.$$

We obtain expressions for the fluid velocity and pressure from (1) by omitting the common exponential $e^{ikx+\Omega t}$

$$v'_{lx} = ik\varphi_l e^{kz}, \quad v'_{lz} = k\varphi_l e^{kz},$$
$$p'_l = -\rho_l(kv_l + \Omega)\varphi_l e^{kz}. \tag{12}$$

From (1b) we obtain an expression for the fluid temperature, which substituted into (11) yields the surface temperature $T'_S = T_l(0) + \zeta\frac{dT_{0l}}{dz}$:

$$T'_S = \widetilde{T}'_S + \frac{\rho'_g}{\rho_g}\frac{\delta_0 T_{0S}}{\xi_0 + \chi_l\lambda_1/v_l},$$

$$\widetilde{T}_S = \zeta_0\left\{\frac{\mu^2 Q}{\varkappa_l}F(\mu) + \frac{\lambda_1\frac{dT_{0l}}{dz} - \frac{d^2T_{0l}}{dz^2}}{\lambda_1 + \xi_0 v_l/\chi_l}\right\} + \frac{k\varphi_l}{\chi_l}\left\{\frac{T_{0S}v_l}{\chi_l}F\left(k + \frac{v_l}{\chi_l}\right) + \frac{\mu Q\left(F(\mu+k) - F\left(k + v_l\chi_l^{-1}\right)\right)}{\varkappa_l\left(v_l\chi_l^{-1} - \mu\right)}\right\}, \tag{13}$$

where we have introduced the function

$$F(t) = \left(t^2 + \frac{v_l t}{\chi_l} - k^2 - \frac{\Omega}{\chi_l}\right)^{-1}\left(1 - \frac{t + v_l\xi_0/\chi_l}{\lambda_1 + v_l\xi_0/\chi_l}\right),$$

$$\lambda_1 \equiv \frac{v_l}{2\chi_l} + \sqrt{\frac{v_l^2}{4\chi_l^2} + k^2 + \frac{\Omega}{\chi_l}}.$$

Solving the equation for the vapor (2), we obtain

$$\frac{\rho'_g}{\rho_g} = De^{-\lambda_3 z} - \frac{1}{\gamma}Ce^{-\lambda_2 z}, \quad \frac{p'_g}{p_g} = \gamma De^{-\lambda_3 z},$$
$$\frac{T'_g}{T_g} = (\gamma - 1)De^{-\lambda_3 z} + \frac{1}{\gamma}Ce^{-\lambda_2 z},$$
$$v'_{gx} = -ik\frac{\Omega - \lambda_3 v_g}{\lambda_3^2 - k^2}De^{-\lambda_3 z} + \lambda_2 Ae^{-\lambda_2 z},$$
$$v'_{gz} = \lambda_3\frac{\Omega - \lambda_3 v_g}{\lambda_3^2 - k^2}De^{-\lambda_3 z} + ikAe^{-\lambda_2 z}, \tag{14}$$

where

$$\lambda_2 \equiv \Omega/v_g;\ \lambda_3 \equiv \frac{-\Omega v_g \pm c_S\sqrt{\left(c_S^2 - v_g^2\right)k^2 + \Omega^2}}{c_S^2 - v_g^2}; \quad c_S^2 \equiv \gamma p_g/\rho_g.$$

The sign in front of the root is selected from the condition of the solution decreasing as $z \to \infty$. Substituting the expressions for ρ'_g, T'_g and T'_S in (10), we express the coefficient C in terms of D and T_S:

$$C = -\gamma\left\{-\frac{\tilde{T}_S}{(a-b)T_{0S}} + \frac{a(\gamma-1)+b}{a-b}D\right\}. \tag{15}$$

In obtaining (15) it was assumed that $\xi_0 \sim u^2/T_S^2 \gg 1$, here the components proportional to ρ_g' can be neglected in the expression for T_S' in (13).

Substituting (12)-(14) into the boundary conditions (5), (6), (8), (9), we obtain a system of linear algebraic equations

$$\Omega\zeta_0(\rho_l - \rho_g) = k\varphi_l\rho_l - \rho_g\left(\lambda_3\frac{\Omega - \lambda_3 v_g}{\lambda_3^2 - k^2}D + ikA\right) + \frac{v_g}{a-b}\frac{\tilde{T}_S}{T_{0S}} - \frac{a\gamma v_g}{a-b}D; \tag{16}$$

$$(\Omega - kv_l)\rho_l\varphi_l + (\rho_l - \rho_g)g\zeta_0 + \alpha k^2\zeta_0 = 2\rho_l v_l\left(-ikA + \lambda_3\frac{\lambda_3 v_g - \Omega}{\lambda_3^2 - k^2}D\right) + \frac{\rho_l v_l v_g}{a-b}\frac{\tilde{T}_S}{T_{0S}}; \tag{17}$$

$$ik\varphi_l + ik(v_l - v_g)\zeta_0 = ik\frac{-\Omega + \lambda_3 v_g}{\lambda_3^2 - k^2}D + \lambda_2 A; \tag{18}$$

$$\Omega\zeta_0 = k\varphi_l - v_l\frac{u}{T_{0S}^2}\tilde{T}_S. \tag{19}$$

Eliminating the coefficients A and D from (16) and (18) and substituting them into (17), we obtain

$$\left\{\Omega - kv_l - 2kv_l\frac{k}{\lambda_2} + kv_l f(\lambda_3)\left(\frac{\rho_l}{\rho_g} + \frac{k}{\lambda_2}\right)\right\}k\varphi_l + \\ + \left\{\omega_0^2 + 2k^2 v_l(v_g - v_l)\frac{k}{\lambda_2} - kv_l\left[\Omega\left(\frac{\rho_l}{\rho_g} - 1\right) + \frac{k^2}{\lambda_2}(v_g - v_l)\right]f(\lambda_3)\right\}\zeta_0 = 0, \tag{20}$$

where

$$\omega_0^2 = \left(1 - \frac{\rho_g}{\rho_l}\right)gk + \frac{\alpha}{\rho_l}k^3;$$

$$f(\lambda_3) \equiv \left[2\frac{(\lambda_3 - k^2\lambda_2^{-1})(\lambda_3 - \lambda_2)}{\lambda_3^2 - k^2} - \frac{a\gamma}{a-b} - \frac{c_S^2}{v_g^2}\right] \times \left[\frac{(\lambda_3 - k^2\lambda_2^{-1})(\lambda_3 - \lambda_2)}{\lambda_3^2 - k^2} - \frac{\gamma a}{a-b}\right]^{-1}.$$

The compatibility condition for the system (19) and (20) governs the dependence of the increment Ω on the wave number k of the disturbance.

Let us first consider the limit case when the last term in the right side can be neglected. Substituting $\Omega\zeta_0 = k\varphi_l$ in (20), we obtain the dispersion equation

$$\Omega^3 + \Omega^2 kv_l(f(\lambda_3) - 1) + \Omega\left(\omega_0^2 + k^2 v_l v_g(f(\lambda_3) - 2)\right) + k^3 v_l v_g(v_g - v_l)(2 - f(\lambda_3)) = 0. \tag{21}$$

This equation simplifies substantially in the limit case $v_g \ll c_S$, $v_g = c_S$, $v_g \gg c_S$. In the subsonic vapor flow mode, the function $f(\lambda_3)$ equals $f \simeq 2 + \Omega/kv_g$ approximately, and (21) reduces to the form [2]

$$\Omega^2\left(1 + \frac{\rho_g}{\rho_l}\right) + 2\Omega kv_l + \omega_0^2 - k^2 v_l(v_g - v_l) = 0.$$

For $kv_g(v_l/v_g)^{1/2} > \omega_0(k)$ an aperiodic instability occurs in the plane evaporation wave front. If $kv_g(v_l/v_g)^{1/2} \gg \omega_0(k)$ then the instability increment equals

$$\Omega = kv_g(v_l/v_g)^{1/2}.$$

In the self-similar vapor escape mode the condition $v_g = c_S$ is satisfied. In this case $f(\lambda_3) \equiv f_0 = ((3+\gamma)a - 3b)(a(1+\gamma) - b)^{-1}$ (we later assume $a > b$), and the dispersion equation is reduced to the form

$$\Phi(\Omega) \equiv \Omega^3 + \Omega^2 kv_l(f_0 - 1) + \Omega\left(\omega_0^2 - k^2 v_l v_g(2 - f_0)\right) + k^3 v_g v_l(v_g - v_l)(2 - f_0) = 0. \tag{22}$$

This equation has a root with Re $\Omega > 0$ upon satisfying the condition

$$k^2 v_g(v_g - v_l)\frac{2 - f_0}{f_0 - 1} > \omega_0^2 - k^2 v_l v_g(2 - f_0).$$

For $\omega_0(k) \ll (2 - f_0)^{1/3} kv_g(v_l/v_g)^{1/3}$ we have

$$\Omega_1 = -kv_g(v_l(2-f_0)/v_g)^{1/3},$$
$$\Omega_{2,3} = \left(\pm i\frac{\sqrt{3}}{2}+\frac{1}{2}\right)kv_g(v_l(2-f_0)/v_g)^{1/3}. \tag{23}$$

As $\omega_0 \to \infty$ the expressions for the roots have the form

$$\Omega_1 = -(2-f_0)\frac{k^3v_g^2v_l}{\omega_0^2},$$
$$\Omega_{2,3} = \pm i\omega_0\left[1-(2-f_0)\frac{v_lv_gk^2}{2\omega_0^2}\right]+kv_l\left[\frac{1-f_0}{2}+(2-f_0)\frac{k^2v_g^2}{2\omega_0^2}\right]. \tag{24}$$

Therefore, in contrast to the case of the subsonic vapor flow regime, the plane evaporation wave front turns out to be absolutely unstable for $v_g = c_S$ since, for example, the condition $v_g \gg \min(\omega_0(k)/k)$ is always satisfied in laser experiments. For small $\omega_0(k)$ the instability increment equals $\mathrm{Re}\,\Omega \sim kv_g(v_l/v_g)^{1/3}$ in order of magnitude and exceeds the increment for an incompressible fluid.

For a substantially supersonic gas flow regime we have

$$f(\lambda_3) = \left(\pm\frac{2ikc_S}{\Omega}-\frac{a\gamma}{a-b}\right)\left(\pm i\frac{kc_S}{\Omega}-\frac{a\gamma}{a-b}\right)^{-1}.$$

The signs (+) and (–) correspond to two different values of the root in the expression (14) for λ_3. For definiteness we select the sign (+). The complex-conjugate expression is obtained when the other sign is selected for Ω. In case $\Omega < kc_S$ we have $f(\lambda_3) \simeq 2-\frac{ia\gamma}{a-b}\frac{\Omega}{kc_S}$, and we obtain from (22)

$$\Omega^2 - i\Omega\frac{kv_lv_g}{c_S}\frac{\gamma a}{a-b}+\omega_0^2(k)+i\frac{k^2v_g^2v_l}{c_S}\frac{a\gamma}{a-b} = 0.$$

This equation always has a root $\Omega > 0$. For $\omega_0 \ll kv_g(v_l/c_S)^{1/2}$ the instability increment equals $\mathrm{Re}\,\Omega = kv_g\left(\frac{v_l}{2c_S}\frac{\gamma a}{a-b}\right)^{1/2}$, which also exceeds the increment in the incompressible fluid. The expression obtained is valid under the condition $c_S^2/v_l \gg v_g \gg c_S$. In the other limit case $v_g \gg c_S^2/v_l$ $f(\lambda_3) \simeq 1$ and the dispersion equation reduces to the form

$$\Omega^3+\Omega(\omega_0^2-k^2v_lv_g)+k^3v_lv_g^2 = 0.$$

The instability increment equals $\mathrm{Re}\,\Omega = (1/2)kv_g(v_l/v_g)^{1/3}$ in this case for $\omega_0 \ll kv_g(v_l/v_g)^{1/3}$.

It is therefore seen that for vapor efflux velocities commensurate with the speed of sound, the plane evaporation wave front turns out to be absolutely unstable.

Let us investigate the influence of the temperature disturbances in the fluid for the case of self-similar vapor escape when $v_g = c_S$. Considering the term with $\tilde{T}_S$ in (19) as a small addition, we find the correction to the natural frequencies of the system. Substituting $\Omega = \Omega_0 + \delta$ into (19) and (20), we obtain

$$\delta\left.\frac{d\Phi}{d\Omega}\right|_{\Omega_0} = -\frac{v_lu}{T_{0S}}\left\{\frac{\mu^2Q}{\varkappa_l}F(\mu)+\frac{\lambda_1\frac{dT_{0l}}{dz}-\frac{d^2T_{0l}}{dz^2}}{\lambda_1+\xi_0v_l/\chi_l}+\frac{\Omega}{\chi_l}\left[\frac{T_{0S}v_l}{\chi_l}F\left(k+\frac{v_l}{\chi_l}\right)+\right.\right.$$
$$\left.\left.\frac{\mu Q\left(F(\mu+k)-F\left(k+\frac{v_l}{\chi_l}\right)\right)}{\varkappa_l(v_l/\chi_l-\mu)}\right]\right\}\times\left(\Omega_0-kv_l-2kv_l\frac{kv_g}{\Omega_0}+kv_lf_0\left(\frac{\rho_l}{\rho_g}+\frac{kv_g}{\Omega_0}\right)\right). \tag{25}$$

In the limit case of surface absorption, (25) simplifies for $\mu \gg \sqrt{\Omega_0/\chi_l}$, $v_lu^2/\chi_lT_{0S}^2$. For $kv_g \gg |\Omega_0| \gg kv_l$ we obtain from (25)

$$\delta = -\frac{v_l^2u}{\chi_lT_{0S}}\left(\frac{d\Phi(\Omega_0)}{d\Omega}\right)^{-1}\frac{k^2\Omega_0v_gf_0}{\lambda_1+\xi_0v_l/\chi_l}. \tag{26}$$

For $\omega_0 \ll |\Omega| \sim kv_g(v_l/v_g)^{1/3}\Omega_0$ there is given (23), and the condition of smallness of the temperature additions $\delta \ll |\Omega_0|$ has the form

$$\left(\frac{v_g}{v_l}\right)^{1/3} \gg \frac{u}{T_{0S}} \frac{1}{\xi_0 + (\chi_l |\Omega_0|)^{1/2}/v_l},$$

which is known to be satisfied under the considered conditions of fluid evaporation by a powerful radiation flux.

In the opposite limit case, when $i\Omega_0 \simeq \omega_0 \gg kv_g(v_l/v_g)^{1/3}$, we obtain from (26)

$$\delta = -\frac{u}{T_{0S}} \frac{ik^2 v_g v_l f_0}{\omega_0 (\xi_0 + (-i\omega_0 \chi_l / v_l^2)^{1/2})}. \tag{27}$$

For $\xi_0 \ll (\chi_l \omega_0 / v_l^2)^{1/2}$ this expression agrees to the accuracy of the factor f_0 with the expression for the instability increment of capillary waves obtained in [4]. The complete expression for the natural frequency is given by the sum of the expressions (24) and (27).

The results obtained above indicate the importance of taking account of the vapor dynamics. The method of describing the phase transition region as a hydrodynamic discontinuity is valid in considering disturbances with wavelengths substantially greater than the thickness of the transition region, i.e., for $kl \sim kav_g/v_l \ll 1$, where l is the particle mean free path in the gas, and a is a quantity on the order of the interatomic spacing in the fluid. For $kl \gtrsim 1$ the kinetic equation must be used to describe the vapor dynamics. Moreover, in considering shortwave disturbances it is necessary to take account of viscous damping in the fluid since the condition $\nu k^2 \ll \omega_0$ can be spoiled.

In the region of large energy fluxes when $u^2 v_l^2 / T_{0S}^2 \chi_l \gg \omega_0$, $kv_g(v_l/v_g)^{1/3}$ all the hydrodynamic motions become insignificant and the dispersion equation reduces to the form

$$\Omega + \frac{v_l u}{T_{0S}} \left\{ \frac{\mu^2 Q}{\varkappa_l} F(\mu) + \frac{\lambda_1 \frac{dT_{0l}}{dz} - \frac{d^2 T_{0l}}{dz^2}}{\lambda_1 + \xi_0 v_l / \chi_l} \right\} = 0, \tag{28}$$

investigated in [5], where it is shown that for $Q > Q_{thr}$ the expression (28) has a solution with $\Omega > 0$ where the maximum instability increment is achieved for $k \gtrsim \mu$ and equals $\Omega_{max} \sim v_l^2 u^2 / \chi_l T_{0S}^2$ in order of magnitude.

Therefore, the main mechanism resulting in instability of the plane fluid evaporation wave front in the long-wavelength spectrum range is the mechanism proposed by Landau which is related to the vortical nature of the vapor motion. In contrast to the theory of slow combustion, instability development is possible in the evaporation wave at vapor efflux velocities close to the speed of sound, for any energy flux densities, and is not of purely aperiodic nature.

Instability development can result in a number of physical phenomena already discussed in [3-6]. In particular, the hydrodynamic instability considered in this paper can result in deformation of the liquid surface under a laser beam. The analogy with the theory of slow combustion can apparently turn out to be useful even in the examination of other questions associated with the process of evaporation of condensed media by powerful radiation flux. Thus, the shape of the cavern for a so-called "dagger" fusion of metals [7] turns out to be analogous, from this viewpoint, to the shape of a stationary flame in a tube [3].

The authors are grateful to A. A. Vedenov for constant attention to the research and to S. I. Anisimov for discussion and useful remarks.

LITERATURE CITED

1. S. I. Anisimov, Ya. A. Imas, G. S. Romanov, and Yu. V. Khodyko. Action of High Power Radiation on a Metal [in Russian], Nauka, Moscow (1970).
2. L. D. Landau and E. M. Lifshits, Mechanics of Continuous Media [in Russian], GITTL, Moscow (1953).
3. Ya. B. Zel'dovich, G. I. Barenblatt, V. B. Librovich, and G. M. Makhviladze, Mathematical Theory of Combustion and Explosion [in Russian], Nauka, Moscow (1980).
4. A. A. Samokhin, "On hydrodynamic disturbances of a fluid surface under developed evaporation conditions," Kratk. Soobshch. Fiz., No. 8, Foz. Inst. Akad. Nauk SSSR (1980).
5. S. I. Anisimov, M. I. Tribel'skii, and Ya. G. Epel'baum, "Instability of the plane evaporation front during interaction of laser radiation with a substance," Zh. Eksp. Teor. Fix., 78, No. 4 (1980).

6. E. B. Levchenko and A. L. Chernyakov, "Instability of surface waves in an inhomogeneously heated fluid," Zh. Eksp. Teor. Fiz., 81, No. 1 (1981).
7. F. V. Bunkin and M. I. Tribel'skii, "Nonresonance interaction of powerful optical radiation with a fluid," Usp. Fiz. Nauk, 130, No. 2 (1980).