INTERACTION BETWEEN A LIQUID BATH AND A GAS JET FOR DIFFERENT DEGREES OF ASSIMILATION

V. A. Surin, V. K. Erofeev,
A. S. Grigor'yants, O. N. Zasukhin,
and Yu. N. Nazarov

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The interaction with a liquid jet from immersed and external nozzles as a function of the degree of assimilation of the gas and the methods of blowing are experimentally studied.

In metallurgy and chemical technology, processes and apparatus in which melted materials and solutions are blown with a stream of gas are extremely important. The degree of absorption of the gases of the blast by the liquid bath or, as used in metallurgy, the degree of assimilation (due to absorption, chemisorption, and phase changes), may differ considerably not only for different equipment but may change considerably during the course of a single technological process. It is obvious that the degree of assimilation of a gas not only introduces considerable differences into the hydrogasdynamic tank, which is the basis of mass and heat-transfer processes, but also changes the mechanism of these processes itself.

Compared with unassimilated gas flows, which have been studied in considerable detail in [1–3, etc.], at the present time the hydrogasdynamics of assimilated jets has not been sufficiently investigated. In [4–6] the authors confine themselves to a fairly narrow range of variation of the assimilation coefficients, and they concluded [5] that the degree of assimilation has very little effect on the jet parameters.

In this paper, which differs from the previous investigation [7], we experimentally investigate the features of the hydrogasdynamic interaction for quite different degrees of assimilation of the gas and the liquid.

Experimental Method. The experiments were carried out using the model system described in [7] using a similar method of making measurements and of processing the results. Taking into account the aggressive nature of the majority of simulated systems, we gave particular attention to visual investigations using motion-picture and photographic apparatus. The degree of assimilation for the gas–water system was quantitatively determined as in [8, 9], and for a gas–alkali system using a formal recording of the chemical reactions. We used a variety of model gases and liquids in the experiments, the parameters of which together with the characteristics of the model equipment are shown in Table 1.

When the gas is introduced from the side through a horizontal nozzle immersed in the liquid, we determined the range of the jet l – the length of the horizontal part of the flow from the opening of the nozzle to the intersection of its axis with the external boundary of the flow, the largest diameter of the horizontal part of jet d (ignoring the bubbling gas), the breakaway frequency τ, and the dimensions of the characteristic gaseous formations. When using vertical nozzles we determined, for immersed jets, the depth of introduction of the jet into the liquid l, and the largest jet diameter d; for external jets we measured the depth of the "cavity" h and its greatest diameter d_1 ignoring the "crater" close to the liquid surface, the trajectory and the velocity of the circulation motion of the liquid, the boundary and structure of the bubbling region, and the rise and oscillations of the level of the bath.

Discussion of Results. Side Input of Gas. Figure 1 shows the interaction of the immersed gas jet with the liquid. Analyzing these we notice considerable changes both in the nature of the development of the jet and in the hydrodynamic situation in the bath due to different assimilations of the gas, in which the effect of assimilation is different depending on the gasdynamic modes of discharge from the nozzle.

For gases with weak and medium degrees of assimilation (the physical meaning and quantitative characteristics of these ideas will be considered below) the behavior of the jet discharge from the nozzle is the same.

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TABLE 1. Characteristics of the Experimental Equipment and the Gas – Liquid Vapors Employed

Dimensions, mm, A×B×H	d_0, mm	$G_{\Gamma}\times10^{-3}$, kg/sec	Material	k	a, m/sec	R, N·m/kg·deg	ρ, kg/m³	cm³ gas/cm³ liquid		
								Cl_2	CO_2	H_2O
500×100×1500			Gas							
			Air	1,4	331,5	292,7	1,29			0,0187
	1,82;		Cl_2	1,36	206	116,5	3,22			2,3
400×150×500	2; 3;	1—30	CO_2	1,3	256,7	191,4	1,98			0,878
	4; 5;		H_2O (vapor)	1,33	—	—	—			—
	7; 10		Liquid							
500×300×800			H_2O				1000	2,3	0,9	
			NaOH (15%)				1170	51,1	49,7	
			NaOH (40%)				1430	162,5	161,1	

For side flows we can distinguish four characteristic gasdynamic modes: bubble, pulsation, transient, and jet, considered for an unassimilated gas in [7]. The conditions for any particular mode to build up are determined by the discharge velocity of the gas V_a, and more accurately by the ratio of the velocity of the gas to the velocity of sound in the gas V_a/a, i.e., the ratio of the supply pressure P_0 to the back pressure in the section of the nozzle $P_b = \rho_l g H_l$ (ρ_l and H_l are the density and level of the liquid), and the geometry of the nozzle (the Mach number at the nozzle cross section M_a). Since for assimilated gases (Cl_2, CO_2) the velocity of sound is less than in air, the supply pressures (which determine any particular mode) are correspondingly shifted into the region of lower values of P_0. The frequency of pulsations – breakaway from the nozzle or stable gas "pinch" of coarse gaseous formations – remains within the limits 5-15 Hz. In the transient and jet modes, as K increases the stability of the gas flow increases. The intensity of the pulsations is reduced and the values of the maximum and minimum range l_1 and l_2 [7] approach one another. For an excess pressure $P_0 > (0.4\text{–}0.8)\cdot10^5$ N/m² for gases with an average degree of assimilation at the cross section of the nozzle, a stable jet section occurs, at the end of which a characteristic curvilinear trajectory of floating of the flow due to the action of buoyancy (Archimedes) forces occurs [7]. In this case the expansion angle of the jet Θ = 16–22°. The boundaries of the jets are more stable, and the jet diameter in the immediate vicinity of the nozzle cross section reaches 1.5–2.5 diameters of the output section of nozzle d_0. Changes in the values of l and d for medium-assimilated flows compared with unassimilated gas are small in the bubble and pulsation modes and do not exceed 20–40% at the jet.

At the same time, for average assimilation of the gases in the jet mode considerable differences are observed in the hydrodynamic situation in the bath. For intense blowing for weakly and unassimilated jets, the dimensions of the bubble region are considerable: Gas with velocities up to 1.5–4 m/sec floats up in the form of large masses, and close to the nozzle wall an additional intense circulation region occurs with a high gas content and average velocities of up to 1.0–1.5 m/sec. The whole bath, with the exception of the region under the nozzle, is set in motion with average velocities of up to 0.5–0.8 m/sec (reaching 1.5–2 m/sec close to the surface), and is intensely saturated with gas bubbles, which increase the initial level of the liquid H_l by a factor of 1.2–1.5. In the region of the output at the surface of the bubbling gas considerable spikes of liquid and surface oscillations are observed, reaching up to $(1.8\text{–}2)H_l$. In the case of average assimilation in the direction toward the surface, the dimensions of the bubbling region and the individual floating gaseous masses, their number and rate of floating (which approximates to the rate of free bubbling) decrease considerably. The circulation in the bath is reduced due mainly to floating gas, gaseous formations close to the nozzle wall practically disappear and liquid spikes and oscillations of the surface decrease. The increase in the level due to gas saturation does not exceed several percent. Of the four hydrodynamic modes (bubble, jet, foam, and splashing) characteristic for unassimilated gases [10], in the case of average assimilation in the bath only the bubble and jet modes averaged over the whole volume of the bath, and also local foam and bubbling regions, can be realized.

When realizing gasdynamic modes of flow from the nozzle connected with the formation, breakaway, and floating up of individual gaseous masses, reaching, for $d_0 = 1.8\cdot10^{-3}$ m and dimensions $\phi = (20\text{–}40)\cdot10^{-3}$ m (bubble – transient), the conditions for gas assimilation in the bubbling region (it occurs on the surface of the gaseous volumes) are difficult, which does not enable the output of gas at the surface to be liquidated for immersed nozzles up to $(150\text{–}200)d_0$. However, the transfer of the flow into the jet flow mode (increasing P_0) considerably increases the ejection of liquid into the jet and mixing and breakdown of the flow, which intensifies the interaction and enables the ejection of the gas from the bath to be sharply reduced or liquidated for sufficiently high values of K and H_l.

When there is considerable assimilation of gas, the jets undergo more important changes. Thus, in the

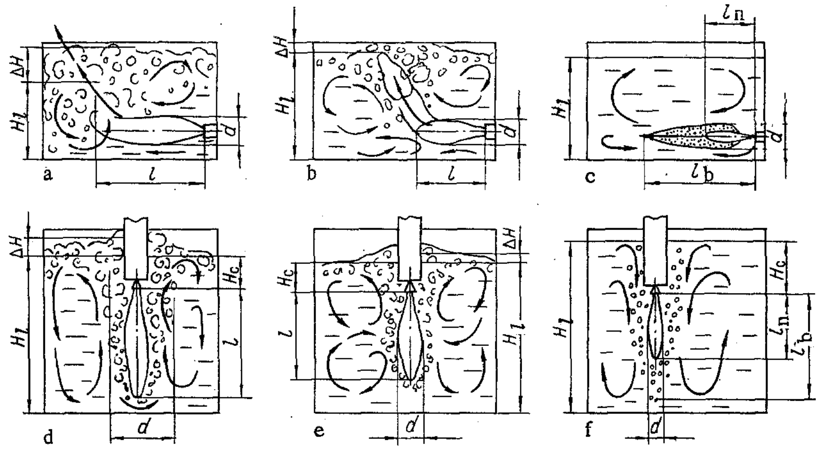

Fig. 1. Interaction with the liquid bath of a gas flow from an immersed nozzle. Weak assimilation of the gas, air—water: a) $d_0 = 3 \cdot 10^{-3}$ m, $P_0 = 2.3 \cdot 10^5$ N/m^2; d) $d_0 = 4 \cdot 10^{-3}$ m, $P_0 = 2.5 \cdot 10^5$ N/m^2. Average assimilation of the gas: b) CO_2 + 40% NaOH, $d_0 = 1.8 \cdot 10^{-3}$ m, $P_0 = 1.5 \cdot 10^5$ N/m^2; e) CO_2 + 40% NaOH, $d_0 = 1.8 \cdot 10^{-3}$ m, $P_0 = 2.2 \cdot 10^5$ N/m^2. Strong assimilation of the gas: c) Cl_2 + 40% NaOH, $d_0 = 1.8 \cdot 10^{-3}$ m, $P_0 = 1.5 \cdot 10^5$ N/m^2; f) Cl_2 + 40% NaOH, $d_0 = 1.8 \cdot 10^{-3}$ m, $P_0 = 2 \cdot 10^5$ N/m^2.

bubble flow modes when $P_0 \leq (0.05\text{–}0.15) \cdot 10^5$ N/m^2 (depending on the value of K) the gas flow in the section of the nozzle practically disappears and the entrance of liquid, intensively dissolving gas, into the nozzle and pipeline is possible. At a pressure $P_0 = (0.1\text{–}0.3) \cdot 10^5$ N/m^2 the flow modes are similar to the pulsation modes, studied in [7], for nonassimilated gas. They are characterized by the formation and breakaway (at a frequency of 5–10 Hz) of individual large bubbles with $\phi = 15\text{–}30 \cdot 10^{-3}$ m ($d_0 = 1.8 \cdot 10^{-3}$ m). For $P_0 > (0.2\text{–}0.5) \cdot 10^5$ N/m^2 (lower values correspond to higher values of K) the assimilation processes in the turbulent two-phase flow formed occur much more intensively than at the surface of the individual gas volumes. As a result, a jet-mode of flow is realized characterized by flow stability, the absence of a pulsating boundary layer, and of longitudinal jet pulsations [7], and considerably reduced dimensions l and d of the jet. In this mode the flow axis is horizontal. The absence of large gaseous masses and, consequently, of Archimedes buoyancy forces, does not cause curvature of the trajectories. Above the jet there are practically no gas bubbles. In the jet itself one can distinguish a gas "nucleus" slightly varying along the length l_n, the shape of which for some K depends on the Mach number at the section of the nozzle, and for constant gas entry conditions, on K. The nucleus changes into a perturbed multiphase liquid containing small gas bubbles ($\phi \leq (1\text{–}2) \cdot 10^{-3}$ m), and interaction products, a region of length l_b. Lower along the flow the jet changes into a moving flow of liquid consisting of reaction products and individual unassimilated tiny gas bubbles (as K increases the number and dimensions of the latter contract). An increase in P_0 hardly changes the parameters of the gas nucleus. As K increases the length of the nucleus contracts. Since, irrespective of the degree of assimilation of the gas, the jet momentum is transferred to the liquid flow, when P_0 increases the value of l_b also increases. However, an estimate of the total length of the moving horizontal flow is difficult to make due to the weak optical contrast between the moving liquid with respect to the only slightly moving surrounding medium. The average velocity in the horizontal flow determined from the rate of displacement of a hydrokinematic indicator [7] reaches (0.4–0.6)m/sec for $P_0 = (1\text{–}2) \cdot 10^5$ N/m^2. The average velocities of circulation flow in the bath due to nonsymmetrical input and ejection in the jet are small and do not exceed hundredths of a meter per second. In the case of a very asymmetric gas the bubbling region practically disappears, there is no rise in the level of the bath, and liquidation of the output of gas at the surface eliminates spikes of liquid and waviness.

Top Supply of Gas. As can be seen from Fig. 1, for top jets one obtains gasdynamic flow modes similar to those considered previously. In the bubble, pulsation, and transient modes [7], large gas bubbles of diameter $(10\text{–}30) \cdot 10^{-3}$ m ($d_0 = 1.8 \cdot 10^{-3}$ m) separated from the end of the flow with frequency 4–6 Hz float upwards, flow around the main jet and screen the gas from the liquid — assimilation both in the jet and in the bubbles is reduced. The latter determines the large instability of the boundaries of the jet and the amplification of the longitudinal pulsations, and for the whole flow there is a deviation from the nozzle axis by 5–10°.

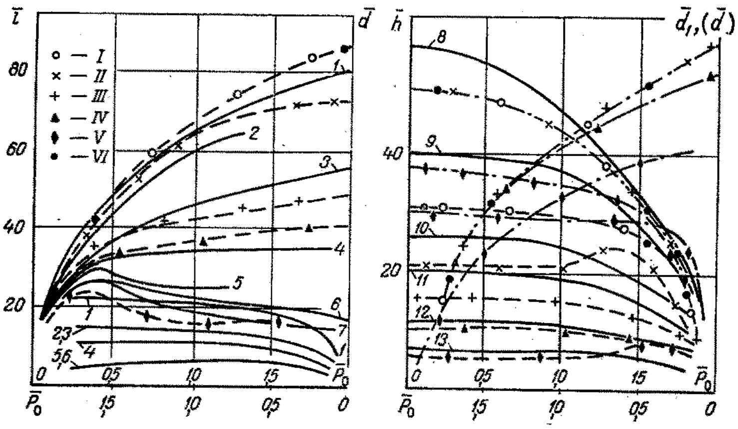

Fig. 2. Experimental curves of the maximum dimensionless values of the length $\bar{l} = l_{max}/d_0$ (the range for the side nozzle) and diameter $\bar{d} = d/d_0$ of the jet from an immersed nozzle, depth $\bar{h} = h_{max}/d_0$ and diameter $\bar{d}_1 = d_1/d_0$ of a cavity for a remote jet as a function of the dimensionless pressure $\bar{P}_0 = P_0/P_n$ for different degrees of assimilation of the gas K and the corresponding approximation formulas. The continuous line is for a side nozzle and the approximation formulas; the dashed lines are for a top immersed nozzle; the dash–dot line is for a top nonimmersed nozzle; the diameter of a crater in the region of the surface of the liquid (the crater) $\bar{H}_c = H_c/d_0$ = 10–30. 1) Air–water; 2) $Cl_2 + H_2O$; 3) CO_2 + 40% NaOH; 4) Cl_2 + 15% NaOH; 5) Cl_2 + 40% NaOH; 6,7) heated water vapor–water, 6) T_l = 35°C, 7) T_l = 25°C, all $d_0 = 1.8 \cdot 10^{-3}$ m. I) N_2 + 15% NaOH; II) CO_2 + 15% NaOH; III) Cl_2 + (6–10%) NaOH; IV) Cl_2 + (15–20%) NaOH; V) Cl_2 + 40% NaOH, all $d_0 = 1.8 \cdot 10^{-3}$ m; VI) air–water, $d_0 = 4 \cdot 10^{-3}$ m. The approximation formulas: 8) [4]; 9) [12]; formula c): 10) for n = 1; 11) 0.5; 12) 0.1; 13) 0.03. In the case of strong assimilation by l_{max} and d_{max} we mean l_n and d_n.

In the case of average assimilation of the gas when $P_0 \geq (0.3\text{–}0.8) \cdot 10^5$ N/m² a jet mode is realized. At a certain distance from the section of the nozzle at the boundaries of the jet large gas formations of diameter $(20\text{–}40) \cdot 10^{-3}$ m occur, which break away with a frequency of 5–10 Hz and which float along the jets and the nozzle. During bubbling the bubbles are partially assimilated, but for all the immersed nozzles investigated (H_c = 0–0.2 m) the output of gas at the surface remain the same. At the end of the jet small bubbles of diameter $(1\text{–}5) \cdot 10^{-3}$ m are formed, which are carried downwards in the flow to a distance of up to half the length of the jets. For higher values of K they completely assimilate during this time. When K is reduced, reaching maximum immersion, the bubbles begin to float upward but are completely assimilated before emerging at the surface. A large part of the jet, when keeping values of l close to the unassimilated gas, unlike the latter is not surrounded by floating gaseous masses, as a result of which the jet diameter is considerably reduced and the direction of motion of the circulating liquid close to the jet is oriented deep into the flow unlike weakly and unassimilated jets, where the direction always coincides with the direction of bubbling, i.e., to the surface. In the case of strong assimilation of the gas in the pressure range $P_0 \leq (0.1\text{–}0.3) \cdot 10^5$ N/m² there is a pulsating mode with the formation of individual large bubbles, which in the process of floating upward are able to completely assimilate and emerge at the surface. For large P_0 a jet mode is established with a nucleus d_n and a perturbed region l_b. The jet diameter in the region of the nozzle section does not exceed $(1.5\text{–}2)d_0$. The jet length is close to the values of l for a side nozzle, whereas the reduction in d_n compared with the unassimilated gas for the top jet is much greater. At the surface of the bath there are no spikes and the surface is calm. The intensity of the circulations of liquid in the neighborhood of the jet is smaller than when blowing an unassimilated gas but the excited jet of vertical liquid flow acts at much greater depths in the bath, introducing gas into it, transferring momentum to it, and bringing about additional motion. Since with the top jet bubbles of gas, until they emerge at the surface, will traverse practically two bubbling levels (downward with respect to the flow and in the direction of the surface), the latter enables the height of the bath to be reduced or, keeping the height the same, to ensure increased gas discharge, eliminating overshoots of gas from the bath.

In the case of blowing from a remote nozzle over the level of the liquid, due to intense ejection of atmospheric air in the jet and the formation of a "protective jacket," the nature of the introduction of the jet into the liquid and the depth at which cavities are formed are fairly close for all the gases investigated, while the degree of assimilation of a wide range of values of K has only a small effect on the depth at which the cavities are formed. This result corresponds to the conclusions reached in [5, 6]. However, for intense blowing of assimilated gas, beginning at certain values of P_0, depending on d_0, H_c, and K, a reduction in h is observed. The effect of K on the diameter of a cavity is more considerable. Although the change in d_1 also does not exceed 20–30%, the structure of a cavity, the nature of the overshoots of gas, and the liquid state of the surface depends to a considerable extent on K.

Parameters of the Jet. Figure 2 shows the experimental relations

$$\bar{l} = l/d_0 (\bar{h} = h/d_0) = f(P_0, K) \quad \bar{d} = d/d_0 \, (\bar{d}_1 = d_1/d_0) = f(P_0, K)$$

for side and top jets, reflecting the complex relationship between the geometrical parameters of the jet and a cavity on the feed pressure P_0, the degree of assimilation of the gas by the bath K, and the method of blowing. It can be seen from the figure that in the jet mode the effect of the degree of assimilation is quite considerable, and when K is increased several tens of times the values of l_n decrease by a factor of 3–5, whereas in the bubble, pulsation, and transient gasdynamic modes over this range of values of K the differences do not exceed 20–30%. For gas flows with $K \leq (2\text{–}3)$ ($Cl_2 - H_2O$, CO_2 + NaOH with concentrations of less than 15%, and all gases which dissolve only slightly in water), maximum $\bar{l}_2$ (constructed in Fig. 2), the minimum $\bar{l}_1$, the lengths of the jets differ from the similar values $\bar{l}_{1,2}$ for unassimilated gas [7] by not more than 10–15%, which is within the limits of experimental error. Consequently, one can neglect changes in the length, and the side and vertical immersed jets, as also the hydrodynamic situation in the bath, and we have weak assimilation of the gas. For weakly assimilated side jets the transverse dimensions ($\bar{d}$) of the flow are close to unassimilated gases. However, the diameter of the top immersed jets, even for weak assimilation due to contraction of the total amount of the main jet of gas floating to the boundaries and a reduction in the dimensions of the bubbles, is reduced considerably, and for K = 2–3 (for Cl_2 and CO_2) in the jet mode by 30–60% less than the similar values compared with unassimilated gas.

In the case of average assimilation of gas (K = 5–20 for Cl_2 and CO_2 with concentrated alkali) in the region of jet flow the values of $\bar{l}$ fall by 20–50%, both for top and for side jets. In this case, due to the more intense interaction at the boundaries of the jet, the values of $\bar{d}$ for side nozzles decrease by 20–30%, and additional liquidation of a large part of the backward flow (bubbling along the main jet) reduces the transverse dimensions of the top immersed jets by a factor of 2–2.5. In this range of K it is necessary also to make a correction for the hydrodynamic characteristics of the bath taking into account the factors considered previously. Finally, for K > 30 for Cl_2 and when using vapor and water* [11] with T_b = 300°C and T_l < 40°C (for CO_2 these conditions were not realized), in the jet mode the values of l_n may fall by a factor of 2–5, in which case the conditions for strong assimilation are satisfied.

In this case, intensification of the interaction at the boundaries of the jet and liquidation of the bubbling along the jet leads to a reduction in the transverse dimensions of the side jet (d_n) by a factor of 2–4, while the transverse dimensions of the top immersed jet are reduced by a factor of 5–8. Under strong assimilation conditions there is practically no bubbling region, no overshoots of gas and liquid, and no increase and oscillations of the bath level.

Hence, the physical meaning of the ideas of weak, medium, and strong assimilation is determined by the contraction in the jet length: less than 15% is weak, up to 50% is medium, and higher than 50% is strong. The remaining parameters of the flow are determined within the framework of the achieved degree of assimilation.

Comparison of the diameters of the reaction zone for side and top immersed jets confirms the qualitative conclusion reached in [7] regarding the identical nature of the mechanism of the flow of gases from an immersed nozzle for an orientation of the nozzle axis with respect to the horizontal. In fact, liquidation at the boundaries of the top jets of external bubbling gas flow leads to convergence of their transverse dimensions with the horizontal part of the side jet, which is particularly characteristic for the jet gasdynamic mode and occurs for any degree of assimilation.

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*R. D. Kuzemko and O. N. Shlik, Zhdanov Metallurgical Institute, participated in the experiments with heated vapor.

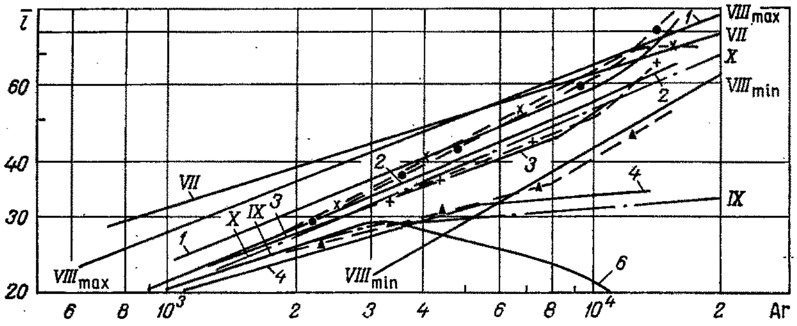

Fig. 3. Dependence of the dimensionless length $\bar{l}$ of the jet on the Archimedes number (Ar): VII) calculated from [13]; $VIII_{max,min}$ calculated from [7]; IX) according to (c); X) according to (b); 1) according to (a). The remaining notation is the same as in Fig. 2.

Investigation of the geometry of the cavity formed when a gas jet is introduced into the liquid from a nonimmersed nozzle, confirms that in the case of open ("jet") cavities the depth and diameter of the reaction zone are close in value. The greatest transverse dimensions of a cavity (close to the liquid surface) in this case is fairly satisfactorily described by the relation a) $d_1/d_0 = n^{1/3}Ar^{1/2}$ for n = 0.1 [4] for nonassimilated flows and gases which we have referred to as medium and weak degrees of assimilation (8, Fig. 2). The diameter of the jet cavity for strong assimilation of the gas is better described by the expression b) $d_1/d_0 = 1 + 0.67\,Ar^{0.42}$ (12) (9, Fig. 2).

When the jet cavity changes into a closed ("bubbling") cavity (the conditions for this transition have been analyzed in [14]), its greatest diameter is extended (with the exception of a blurred zone close to the crater of the cavity) and becomes close to the transverse dimensions of the top immersed jet. In this case, for all gases with the exception of strongly assimilated gases, approximation b) introduced above can be used with an error of 20%. For strongly assimilated gases the diameter of the bubbling cavity can be estimated to a first approximation using the formula c) $d_1/d_0 = n^{1/3}Ar^{1/3}$ for n = 1 (10, Fig. 2). It also holds for a top immersed nonassimilated jet.

The values n = 0.5 (11, Fig. 2) satisfy side unassimilated and top weakly assimilated jets of gas; n = 0.5–0.2 is for gases of medium assimilation, and n = 0.2–0.03 is for strongly assimilated gases (K = 30–160) (12, 13, Fig. 2). In Fig. 3 we show graphs of $\bar{l} = f(Ar)$ in the case of immersed and nonimmersed jets for gases with different degrees of assimilation, which can be approximated by the following equation: $\bar{l} = 0.96 \cdot Ar^{0.45}$ – weak assimilation – a; $\bar{l} = 1.8\,Ar^{0.35}$ – medium assimilation – b; $\bar{l} = 3.0\,Ar^{0.27}$, $Ar \leq 3 \cdot 10^3$; $\bar{l} = 18\,Ar^{0.06}$, $Ar > 3 \cdot 10^3$ – strong assimilation – c (Fig. 3).

NOTATION

H_c and H_l, distance of the nozzle from the level of the liquid and the initial level of the bath; d_0, critical (output) diameter of the nozzle; P_0, excess blowing pressure; l and d, length (range of the horizontal jet) and the largest diameter of the jet; h and d_1, depth of a crater and its greatest diameter for a nonimmersed nozzle; k, ρ, ρ_l, ν, ν_l, adiabatic index, and the density and viscosity of the gases and liquids; ϕ, diameter of the individual gas bubbles; $Ar = V_a^2 \rho / g d_0 \rho_l$, Archimedes' criterion, where V_a is the flow rate of the gas from the nozzle; g, acceleration due to gravity; and K, assimilation coefficient of the gas by the liquid.

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RADIATIVE – CONDUCTIVE HEAT TRANSFER UNDER CONDITIONS OF A REGULAR MODE OF THE FIRST KIND

I. A. Gorban' and Yu. V. Lipovtsev

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The regularities of heating a plane layer of a semitransparent condensed medium with optically smooth surfaces are analyzed under the conditions of a regular mode of the first kind.

The question of the existence of regular modes in partially transparent materials was studied in [1, 2]. It was shown in these papers that regularization of the temperature field sets in for a linear change in the temperature of the layer boundaries, just as this is observed in the classical theory of heat conduction. The present paper is devoted to a theoretical investigation of the regularization process for radiative–conductive heat transfer under conditions of a constant coefficient of convective heat transfer and constant temperature of the environment when the radiant heat flux in the plate is equal to or exceeds the heat flux because of molecular heat conduction.

To clarify the dynamics of temperature field development under the combined heat-transport mechanism, let us consider the problem in the following formulation. Let a semitransparent plate with optically smooth surfaces, within which heat transport is subject to the Fourier general law, have a uniform temperature distribution $T(0, x) = T^{\circ}$ at the initial time $\tau = 0$. The plate is placed in a plane channel (Fig. 1) over which flows a hot gas whose temperature T_e and convective heat-transfer coefficient h_e are given and constant in time. The channel walls are force cooled and their emissivity is one. The thermophysical and radiation characteristics of a partially transparent layer are independent of the temperature.

The process of combined heat transport by radiation and heat conduction is described by a coupled system of essentially nonlinear integrodifferential equations [3]

$$\cos\theta \frac{\partial \Phi^{\pm}}{\partial x} = \mp \alpha\Phi^{\pm} \pm \alpha n^2 B(\lambda, T)/\pi, \tag{1}$$

$$C_\rho \frac{\partial T}{\partial \tau} = K \frac{\partial^2 T}{\partial x^2} + 2 \int\limits_{(\lambda_t)} d\lambda \int\limits_0^{\pi/2} \alpha [\pi (\Phi^+ + \Phi^-) - 2n^2 B] \sin\theta d\theta. \tag{2}$$

Since the emissivity of the surfaces bounding the channel is one, then in practice all the radiation incident is absorbed and none reflected. The intrinsic radiation of the channel surface and the gas can be neglected since the channel walls are cooled, and the optically thick gas layer is considered small. Therefore, the ex-

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