N. V. Nevmerzhitskiy

Russian Federation Nuclear Center,
Nizhniy Novgorod region,
Sarov, Russia
e-mail: postmaster@ifv.vniief.ru

E. A. Sotskov

Russian Federation Nuclear Center,
Nizhniy Novgorod region,
Sarov, Russia

E. D. Sen'kovskiy

Russian Federation Nuclear Center,
Nizhniy Novgorod region,
Sarov, Russia

O. L. Krivonos

Russian Federation Nuclear Center,
Nizhniy Novgorod region,
Sarov, Russia

A. A. Polovnikov

Russian Federation Nuclear Center,
Nizhniy Novgorod region,
Sarov, Russia

E. V. Levkina

Russian Federation Nuclear Center,
Nizhniy Novgorod region,
Sarov, Russia

S. V. Frolov

Russian Federation Nuclear Center,
Nizhniy Novgorod region,
Sarov, Russia

S. A. Abakumov

Russian Federation Nuclear Center,
Nizhniy Novgorod region,
Sarov, Russia

V. V. Marmyshev

Russian Federation Nuclear Center,
Nizhniy Novgorod region,
Sarov, Russia

Study of the Reynolds Number Effect on the Process of Instability Transition Into the Turbulent Stage

The results of the experimental study of the Reynolds number effect on the process of the Rayleigh–Taylor (R-T) instability transition into the turbulent stage are presented. The experimental liquid layer was accelerated by compressed gas. Solid particles were scattered on the layer free surface to specify the initial perturbations in some experiments. The process was recorded with the use of a high-speed motion picture camera. The following results were obtained in experiments: (1) Long-wave perturbation is developed at the interface at the Reynolds numbers $Re < 10^4$. If such perturbation growth is limited by a hard wall, the jet directed in gas is developed. If there is no such limitation, this perturbation is resolved into the short-wave ones with time, and their growth results in gas-liquid mixing. (2) Short-wave perturbations specified at the interface significantly reduce the Reynolds number Re for instability to pass into the turbulent mixing stage.

[DOI: 10.1115/1.4027774]

Introduction

Turbulent mixing (TM) occurring at the propagation of the R–T [1,2] and Richtmyer–Meshkov (R–M) [3,4] instabilities on the interfaces of substances with different densities can lead to a decrease of efficiency in the targets of inertial thermonuclear fusion. At present the researchers attempt to describe these instabilities numerically for taking into account their effect on the processes of energy accumulation in such arrangements.

The process of the R–T instability propagation is conditionally divided into four stages [5]:

- (1) linear (perturbation amplitude increases, the form and symmetry are not changed)
- (2) nonlinear (the perturbation form is changed and the symmetry is broken; the heavy liquid protuberances are narrowed in the form of jets, the light liquid protuberances are widened in the form of round bubbles)
- (3) the stage of the regular mode breakup and transition into the turbulent mixing (the jets start to curve, some of the bubbles enlarge and depress their neighbors)
- (4) the stage of fully developed turbulence (turbulent mixing zone is formed, and its width increases in time)

The results of model experiments are used for the numerical technique testing. The authors know the model experimental studies performed on the assumption of that viscosity negligibly effects turbulent mixing propagation [6,7]. However, the mixing

Contributed by the Fluids Engineering Division of ASME for publication in the JOURNAL OF FLUIDS ENGINEERING. Manuscript received March 10, 2013; final manuscript received May 15, 2014; published online July 9, 2014. Assoc. Editor: David Youngs.

Fig. 1 Experimental scheme

can occur in the viscous media as well. That is why it is important to know the conditions of instability transition into the third (turbulent) stage in the viscous media to test the numerical techniques.

To determine these conditions, three groups of experiments were performed to study the R–T instability propagation at the gas and viscous liquid interface.

The object of the first experimental group is the study of instability propagation under high viscosity of liquid, when the only natural (relatively small) initial perturbations are presented at the interface.

The second experimental group studies the R–T instability propagation if there are natural and specified perturbations at the interface, and the viscosity is varied.

The object of the third experimental group is to study the instability propagation under natural perturbations and relatively high value of viscosity, but with the increased (almost four times) area of the interface if compared with the experiments of the first and the second groups. Such an increase of the area makes it possible to decrease the wall effects on the instability propagation.

The experimental study of this problem is presented in this paper.

Experimental Setup

The experiments were conducted by use of the facility, a scheme of which is shown in Fig. 1.

The facility was the light gas gun consisting of the chamber, cover, optically transparent accelerating channel (made of Plexiglass) with the internal section of Ø 50 mm or □ 80 mm (which was consisted of two sections), a transparent container made of Plexiglass and a diaphragm made of Lavsan film, which covers the bottom channel butt (it was destroyed after explosion). The reference marks were applied on the outside surface of the accelerating channel, with the use of which the flow measurement on the video frames was performed.

The liquid layer (glycerine, its solutions or water) was poured into the container (with the internal section of Ø 42.5 mm or □ 70 mm), which was initially held in the channel by friction forces and an elastic substance. Liquid was poured with the concave meniscus in all the experiments. The channel volumes above and below the container were filled with compressed helium or air under equal pressure. The use of relatively light gases is caused by the high values of sound velocity in them. It leads to the rapid balancing of the pressure above and below the container while filling experimental facility. Besides, the density of helium and air is relatively low ($\rho_{\text{He}} = 0.178 \text{ g/l}$, $\rho_{\text{air}} = 1.2 \text{ g/l}$). That is why the value of the Atwood number A at the surface is close to unity ($A = (\rho_L - \rho_G)/(\rho_L + \rho_G)$, where ρ_L is liquid density, ρ_G is gas density). It is convenient for performing the analysis of experimental results.

After the facility was filled with gas, the diaphragm was destroyed by electric explosion of Nichrome wire pasted on it, and gas from under the container escaped into the atmosphere. The container was accelerated downwards under effect of the pressure above it. The R–T instability was propagated on the

Table 1 Experimental conditions

Experimental group	Test number	Substance	B , mm	P , atm	m , g	T , °C	λ , mm	$\nu = \eta/\rho$, $10^{-3} \text{ m}^2/\text{s}$	g_{max} , m/s^2	λ_p , mm	Re_{max}	Re^*	τ , ms	τ_{exp} , ms
I	902	Glycerine	Ø42.5	1	90.15	20	–	1.18	1466	12.4	10^3	–	0.82	–
	903	Glycerine	Ø42.5	1	90.15	20	–	1.18	1111	13.5	1.4×10^3	–	0.99	–
	904	Glycerine	Ø42.5	1	90.15	20	–	1.18	766	15.3	0.9×10^3	–	1.26	–
	905	Glycerine	Ø42.5	2	90.15	19	–	1.29	3350	10	5×10^3	–	0.49	–
	906	Glycerine	Ø42.5	4	90.15	20	–	1.18	6460	7.5	1.4×10^4	–	0.3	–
	907	Glycerine	Ø42.5	4	142.2	20	–	1.18	2450	10.4	2×10^3	–	0.58	–
	912	Glycerine	Ø42.5	8	90.15	19	–	1.29	15,310	6	1.5×10^4	–	1.18	–
	914	Glycerine	Ø42.5	30	100	20	–	1.18	46,885	3.9	1.6×10^4	–	0.8	–
	915	96% of glycerine	Ø42.5	8	90.15	17	–	0.67	15,485	3.9	1.9×10^4	–	0.14	–
	920	Glycerine	Ø42.5	4	90.1	20	–	1.18	7722	7.1	5×10^3	–	0.27	–
	982	Glycerine	Ø42.5	4	140	21	–	1	4670	7.5	3.6×10^3	–	0.36	–
	983	94% of glycerine	Ø42.5	4.5	104.2	20	–	0.38	7560	3.4	2×10^4	–	0.19	–
	984	92% of glycerine	Ø42.5	4.5	103.7	22	–	0.25	7690	2.5	2.9×10^4	–	0.16	–
II	916	80% of glycerine	Ø42.5	8	91	18	–	0.058	16,459	0.7	2.4×10^5	2.5×10^4	0.06	1.75
	918	Water	Ø42.5	8	91	20	–	0.001	16,330	0.05	3.5×10^6	9.7×10^5	0.02	1.15
	919	80% of glycerine	Ø42.5	4.5	70	20	0.4	0.05	10,156	0.8	3×10^4	2.3×10^4	0.08	2.25
	921	96% of glycerine	Ø42.5	4	90.1	20	3	0.53	7588	4.2	3.3×10^3	10^3	0.21	2.8
	923	Water	Ø42.5	4	90.15	20	0.4	0.001	7520	0.06	3.4×10^6	10^6	0.03	2.6
	924	90% of glycerine	Ø42.5	2.5	68	20	0.4	0.27	8357	2.6	8×10^4	2.3×10^3	0.16	2.5
III	956	Glycerine	□70	5	256	24	–	0.82	10,580	5	7.6×10^3	1.9×10^3	0.19	2.4
	957	Glycerine	□70	2.2	256	24	–	0.82	4853	6.5	2×10^3	0.5×10^3	0.33	4.5
	959	Glycerine	□70	1	218	24	–	0.82	1990	8.8	0.8×10^3	0.7×10^3	0.59	7.8

gas–liquid interface. In time, it leads to the substance mixing. The processes of layer acceleration and instability propagation were recorded by use of a high-speed video camera VS-FAST.

In the first experimental group, the size of the container was equal to 42.5 mm. Glycerine and its water solutions were used as liquid. The initial perturbations at the interface were not specified.

There were only natural perturbations, which were formed because of the molecule escape from the liquid free surface, perturbations from acoustic waves formed under layer movement, and so forth. The estimated size of these perturbations is ≤ 0.01 mm. They are not resolved by the video camera (camera resolution is ≈ 0.05 mm).

Fig. 2 Motion picture of test No. 902 (glycerine, $Re_{max} = 10^3$, $\nu = 1.18 \times 10^{-3}$ m/s², $g_{max} = 1466$ m/s²): the propagation of the single perturbation in the form of a jet directed in the air is observed at the interface. J is the technological joint of the acceleration channel sections.

(a)

(b)

Fig. 3 Motion pictures of experiments in group I: the large jet is propagating at the surface of water solution of glycerine; in time, the separate gas bubbles directed in liquid are formed at the surface, which is free from the jet. J, technological joint of the acceleration channel sections; ES, elastic substance. (a) Test No. 915 (96% of glycerine, $Re_{max} = 1.9 \times 10^4$, $\nu = 0.67 \times 10^{-3}$ m/s², $g_{max} = 15,485$ m/s²); (b) test No. 983 (94% of glycerine, $Re_{max} = 2 \times 10^4$, $\nu = 0.38 \times 10^{-3}$ m/s², $g_{max} = 7560$ m/s²).

Fig. 4 Liquid jet penetration into gas $h_{JET}(2S)$ in experimental group I: the interface oscillation is occurred in area I, the jet is formed in area II (its growth rate depends on the values of viscosity and acceleration), the jet growth rate in area III becomes almost constant (except test No. 904, where the value of the viscosity is considerable)

Fig. 5 Dependence of the Reynolds number Re on displacement $2S$ in experimental group I

The same container was used in the second experimental group. Water and the water solution of glycerine were used as liquid. In some experiments, solid particles made of polypropylene ($\rho \approx 0.91 \text{ g/cm}^3$) with the characteristic size of $\approx 0.4 \text{ mm}$ or 3 mm were scattered at the liquid interface to specify the initial

Fig. 6 Dependencies of the growth rate of liquid jet β_J on the Reynolds number Re . (a) Re was determined at $2S \approx 120 \text{ mm}$ and (b) Re was determined at $2S \approx 280 \text{ mm}$

perturbations. Such particle sizes were chosen in order to maximize the difference of λ in experiments at the existing interface area. The particles were scattered randomly and occupied almost 20% of the layer surface area. The particle density was lower than the liquid density, so while accelerating the layer, they were torn off from the liquid and left the caverns (perturbations) at its surface. Their size (amplitude a_0) was close to the particle size. The wavelength λ of perturbations was equal to $\lambda \approx a_0$. The particles do not practically effect the penetration of mixing zone bubbles in liquid. However, they can somehow effect the penetration of a liquid jet in gas and lead, for example, to a more rapid fragmentation of jets.

In the third experimental group, the layer of glycerine was accelerated in a container with the internal section of $(70 \times 70) \text{ mm}$. The initial perturbations were not specified, and there were only natural perturbations at the interface.

The coefficient of dynamic viscosity η and the density of glycerine, its water solutions, and water were determined according to the tables [8]. The coefficient of the liquid surface tension σ was almost similar and equal to $\sigma = (68-72) \text{ erg/cm}^2$, and coefficients η were different in three orders. It allowed us to study the effect of viscosity on the instability growth at close values of σ . It should be noticed that the effect of surface tension on the perturbation growth is considered in [8,9], in particular.

Some experimental conditions are presented in Table 1.

Experimental Results and Analysis

It is known [10] that viscosity depresses the propagation of short-wave perturbations. When increasing the acceleration (or the Reynolds number), the role of viscosity in the perturbation growth should decay.

At the R-T instability in viscous liquids, perturbation amplitude growth increment with the wave number of $k = 2\pi/\lambda$ equals in the linear approximation [11],

$$\gamma = \sqrt{Akg + \nu^2 k^4} - \nu k^2 \quad (1)$$

The wavelength λ_P of the most rapidly growing harmonic is determined on the condition of $\partial\gamma/\partial k = 0$, whence it follows that

$$\lambda_P = 4\pi \cdot \sqrt[3]{\frac{\nu^2}{Ag}} \quad (2)$$

It appears that liquid viscosity growth at fixed acceleration values leads to the growth of long-wave perturbations.

Perturbation growth transition time into the turbulent stage τ in order of magnitude is in inverse proportion to the maximum perturbation amplitude growth increment [12],

$$\tau = \sqrt[3]{\frac{\nu}{(A \cdot g)^2}} \quad (3)$$

Therefore, liquid viscosity growth at fixed acceleration values g leads to the time delay of transition into turbulent mixing. Acceleration growth leads to the reduction of transition time. In the experiments, τ is assumed to be the time, when the whole ensemble of bubbles and jets appear at the interface.

Fig. 7 Motion pictures of experiments in group II: the initial perturbations lead to rapid generation of the mixing zone of substances even at relatively low value of Re . G.S. – glycerine solution; TMZ – turbulent mixing zone; J – technological joint of the acceleration channel sections. (a) Test No. 919 (80% of glycerine, $\lambda = 0.4$ mm, $Re_{max} = 3 \times 10^4$); (b) test No. 921 (95% of glycerine, $\lambda = 3$ mm, $Re_{max} = 3.3 \times 10^3$); and (c) test No. 916 (80% of glycerine, $Re_{max} = 2.4 \times 10^5$, natural perturbations with the size of $\lambda \leq 0.01$ mm).

Fig. 8 Dependence of gas penetration into liquid h_{LH} on displacement $2S$ in experimental group II. Test Nos. 916 and 918 are without initial perturbations specified; in test No. 919— $\lambda = 0.4$ mm, in test No. 921— $\lambda = 3$ mm, in test No. 923— $\lambda = 0.4$ mm, in test No. 924— $\lambda = 0.4$ mm (data on the plot are approximated)

Some experimental conditions and results are presented in Table 1. The designations include:

B , the internal size of the container; P , the excess pressure of compressed gas (error is ± 0.1 atm); T , ambient temperature; ν , the kinematic viscosity coefficient of liquid (error is $\pm 0.05 \times 10^{-3} \text{ m}^2/\text{s}$);

$g_{\max}$, the maximum layer acceleration in experiment (acceleration was obtained using the dependence of container displacement S on time t);

λ , the characteristic wavelength of the initial perturbation;

$Re_{\max}$, the maximum Reynolds number in experiment; Re^* , the Reynolds number at the moment of turbulent mixing starting; $\tau_{\exp}$, time of instability transition into the turbulent stage obtained

experimentally. The values λ_P and τ are determined from Eqs. (2) and (3), respectively.

In this paper as in [13], the integral Reynolds number was used in the form of $Re = (g^2 \cdot t^3)/\nu$. The linear dimension in this equation is implicitly taken into account by the product of gt^2 .

Each video frame obtained in the experiments was measured using a PC. Besides, the position of flow boundary was measured in (10–40) points, and the results were averaged.

According to the processing results, the dependencies of gas penetration into liquid $h_{LH}(2S)$ and the dependencies of liquid penetration into gas $h_{JET}(2S)$ were plotted. The slope of the linear part of these plots to the X -axis characterizes the rate (velocity) of gas bubbles penetration into liquid β_{LH} or the rate of liquid jet penetration into gas β_J : $\beta_i = dh_i/d2S$.

The measuring errors for the coordinate of linear dimensions in the first experimental group are $\Delta S \approx \pm 0.3$ mm, $\Delta h_{JET} = (0.5–1)$ mm, time error is $\Delta t = 0.5\%$ t , $\Delta \beta_J = \pm 0.02$, where t is the recording time. The errors ΔS and Δt in the second and third experimental groups are similar, $\Delta h_{LH} \approx \pm 0.5$ mm; $\Delta \beta_{LH} = \pm 0.01$. The errors for the coordinate of the measurable point were determined as $\Delta_i = \sqrt{\Delta_1^2 + \Delta_2^2 + \Delta_3^2}$, where Δ_1 is the error of the linear resolution of the video camera (0.05 mm), Δ_2 is the error related to the image parallax (0.1–0.2 mm), Δ_3 is the operator error (0.1–3 mm).

Experimental Group I. In this group of experiments, there were only natural perturbations at the interface.

Figures 2 and 3 show the separate motion pictures of conducted experiments in the equal scale. Figure 4 presents the dependencies of liquid jet penetration into gas $h_J(2S)$, Fig. 5 shows the dependencies of the Reynolds number on the layer displacement $Re(2S)$.

According to Eq. (2), in this experimental group the perturbation with the wavelength equal to 15.3 mm at least is supposed to propagate on the surface of the liquid layer (see Table 1), that is, taking into account the fact that the container diameter equals

Fig. 9 Dependencies of the Reynolds number $Re(t)$ and $Re(2S)$ in experimental group II

42.5 mm, we are supposed to see at least two propagating perturbations on the motion pictures. However, the picture is different.

At $0 < 2S \leq 120$ mm, the interface oscillation occurs (see Figs. 2 and 3 and area I in Fig. 4). Then at $2S \geq 120$ mm the single jet formation is observed, and this jet grows in time. At $120 \text{ mm} < 2S \leq 600$ mm, the growth rate of the jet has a character close to linear (see Figs. 2 and 3 and areas II and III in Fig. 4). In this range of S with the growth of Re from $\approx 10^3$ up to $\approx 3 \times 10^4$, β_j increases from ≈ 0.07 up to ≈ 0.22 . The dependencies of $\beta_j(Re)$ are shown in the plots in Fig. 6 (see the value of β_j in Fig. 4). As

it is seen on the plot, β_j becomes constant with the growth of Re (see Figs. 5 and 6).

The single jet formation can be explained by propagation of a large-scale 3D perturbation, the wavelength of which is compared with the internal section of the container. The certain contribution in this process is possibly made by the liquid meniscus and formation of the wall effect because of high viscosity of the liquid.

According to Eq. (3), turbulent mixing zone on the layer surface, which is free from the jet, is supposed to form at $\tau_{\max} > 1.26$ ms at least (see Table 1). However, in experimental

Fig. 10 Motion pictures of experiments in group III: the time of instability transition into the turbulent stage decreases with the increase of Re . TMZ – turbulent mixing zone; J – technological joint of the acceleration channel sections; AR – auxiliary reference mark. (a) Test No. 959 (glycerine, $Re_{\max} = 8 \times 10^2$); (b) test No. 957 (glycerine, $Re_{\max} = 2 \times 10^3$); and (c) test No. 956 (glycerine, $Re_{\max} = 7.6 \times 10^3$).

Fig. 11 Time dependence of the Reynolds number Re for experimental group III

Fig. 12 Dependence of the time of perturbation growth transition into the turbulent stage τ on the hyperbolic logarithm of the Reynolds number

motion pictures (see Figs. 2 and 3) we observe only separate bubbles, which cannot be considered as the turbulent mixing zone. Therefore, Eq. (3) is not supposed to be used in these experiments.

Thereby, in this experimental group at $Re_{\max} \leq 4.8 \times 10^3$, propagation of the perturbations only occurred at the interface, and the natural perturbations with the size of ≈ 0.01 mm do not lead to the mixing growth.

Experimental Group II. In these experiments, the instability growth at natural and specified perturbations was studied.

Figure 7 shows the separate motion pictures of some conducted experiments of this group in the equal scale. Figure 8 presents the dependencies of gas penetration into liquid $h_{LH}(2S)$, Fig. 9 shows the dependencies of the Reynolds number on time $Re(t)$ and on layer displacement $Re(2S)$.

In all the experiments of this group, the TMZ is propagated at the interface. It should be noticed that the quantitative characteristics of the zone width can be analyzed in the layer displacement range of $0 < S < 50$ mm. At $S > 50$ mm, the container walls are assumed to have an effect on the zone propagation.

According to the experimental results, the following should be noticed:

- The initial short-wave perturbations specified at the interface lead to relatively rapid generation of the mixing zone: in test No. 915 (group I, without initial perturbations, $Re_{\max} = 1.9 \times 10^4$) the jet is propagated; in test No. 921 (with initial perturbations $a_0 = \lambda = 3$ mm) at $Re^* = 10^3$, the mixing zone with large formations is propagated (see Figs. 3(a) and

7(b)), i.e., the initial short-wave perturbations reduce the order of the Reynolds number for the mixing of viscous liquid with gas to start.

- At relatively low values of liquid viscosity and high values of layer acceleration (i.e., at high value of the Reynolds number), the natural (small-scale) perturbations lead to the rapid generation of the mixing zone as well (see Fig. 7(c)).
- In general, the dependence $h_{LH}(2S)$ is shifted upwards with the Reynolds number growth, but the abnormal events have happened as well. In test No. 916 at $Re^* \approx 10^4$, the rapid growth of h_{LH} is observed in the displacement range of $15 \text{ mm} < 2S < 30 \text{ mm}$. Moreover, it is reduced at $2S > 30 \text{ mm}$ (see Fig. 8). It is connected, as in Ref. [9], with the formation (because of viscosity) of perturbations with relatively large wavelengths, which are the origin for large-scale bubbles propagating in liquid with higher velocity than small-scale ones.

Experimental Group III. In these experiments, glycerine was poured in the container with the internal section of (70×70) mm. The initial perturbations were not specified on the layer surface, and there were only natural perturbations. The Reynolds number reached 7.6×10^3 .

Figure 10 shows the separate motion pictures of conducted experiments in the equal scale. The time dependencies of the Reynolds number are presented in Fig. 11.

In experiments of this group, the long-wave perturbation is propagated at the interface at the relatively low Reynolds number. Then it is resolved into the separate bubbles, and the formation of the liquid-gas mixing zone is observed (see Figs. 10 and 11).

Now, we compare the results of experimental groups I and III. At similar values of the Reynolds numbers, the jet is formed in the experiment of group I, and the mixing zone is observed in experimental group III. It can be explained by the fact that in the first case the growth of the long-wave perturbation is limited by the container walls. As a result, it is distorted, which leads to the single jet formation. In the second case, the container does not interfere with the long-wave perturbation growth. During the container acceleration, the perturbation is oscillated and distorted into the short-wave perturbations, which lead to the mixing zone formation. Besides, the large bubble in the left part of the video frames (see Fig. 10) is likely formed because of the interaction between the long-wave perturbation and the container corner, as in [9]. The right part of the container is cut off by a video camera window.

Figure 12 shows the estimated dependence of perturbation growth time of transition into the turbulent stage τ on the hyperbolic logarithm of the integral Reynolds number. It was plotted according to the results of experiments in groups II and III with the natural perturbations.

As it is seen in the plot, the time of perturbation growth transition into the turbulent stage τ in experiments with the viscous liquid is much higher than the value calculated by Eq. (3).

It should be noticed that the obtained mixing mode is not supposed to be interpreted as the mode of the developed turbulence, when viscosity does not have an effect on the mixing. Such mode likely occurs at higher values of the integral Reynolds number. However, such studies are beyond the scope of this paper.

Experimental study with the specified at the interface 3D perturbations with defined amplitude and wavelength is demanded to obtain more specific data about the instability transition into the turbulent stage.

Conclusion

The following results were obtained in the experiments.

The long-wave perturbation is propagated at the interface at the low values of the integral Reynolds number. If such perturbation growth is limited by a hard wall (container), it is distorted and the jet directed in the gas is developed. If there is no such limitation, the long-wave perturbation is resolved into the short-wave ones with time, and their growth leads to the mixing of gas and liquid.

The short-wave perturbations specified at the interface significantly reduce the Reynolds number for instability to pass into the turbulent mixing stage.

References

- [1] Strutt, J. W. (Lord Rayleigh), 1883, "Investigation of the Character of the Equilibrium of an Incompressible Heavy Fluid of Variable Density," *Proc. London Math. Soc.*, **14**, p. 170.
- [2] Taylor, G. I., 1950, "The Instability of Liquid Surfaces When Accelerated in a Direction Perpendicular to Their Planes," *Proc. R. Soc. A*, **201**(1065), pp. 192–196.
- [3] Richtmyer, R. D., 1960, "Taylor Instability in Shock Acceleration of Compressible Fluids," *Commun. Pure Appl. Math.*, **13**(2), pp. 297–319.
- [4] Meshkov, E. E., 1969, "Instability of Gas-Gas Interface Accelerated by Shock Wave," *Izv. AN SSSR, MZhG*, **5**, pp. 151–157 (in Russian).
- [5] Kucherenko, Yu. A., Tomashev, G. G., Shibarshov, L. I., and Pylaev, A. P., 1988, "Experimental Study of Gravitational Turbulent Mixing in Self-Similar Mode," *VANT*, **13**(1), (in Russian).
- [6] Read, K. I., 1984, "Experimental Investigation of Turbulent Mixing by Rayleigh—Taylor Instability," *Physica D*, **12**(1–3), pp. 45–58.
- [7] Meshkov, E. E., 2002, "Rayleigh—Taylor Instability. Study in Laboratory Experiments," p. 68 (in Russian).
- [8] Kaye, G. W., and Laby, T. H., 1962, *Tables of Physical and Chemical Constants*, Longmans, Green, and Co., London/New York.
- [9] Emmons, H. W., Chang, C. T., and Watson, B. C., 1960, "Taylor Instability of Finite Surface Waves," *J. Fluid Mech.*, **7**(2), pp. 177–193.
- [10] Bellman, R., and Pennington, P., 1954, "Effects of Surface Tension and Viscosity in Taylor Instability," *Q. J. Appl. Math.*, **12**, pp. 151–162.
- [11] Sharp, D. H., 1984, "An Overview of Rayleigh—Taylor Instability. Fronts, Interfaces and Patterns," Third Annual International Conference of the Center for Nonlinear Studies, pp. 3–18.
- [12] Bliznetsov, M. V., Nevmerzhiyskiy, N. V., Sotskov, E. A., Tochilina, L. V., Kozlov, V. I., Lychagin, A. K., and Ustinenko, V. A., 2005, "Study of Viscosity Effect on Turbulent Mixing Growth at Gas-Liquid Interface," VIII Zababakhin Scientific Talks, Russia, Snezhinsk, VNIITF.
- [13] Stadnik, A. L., Statsenko, V. P., and Yanilkin, Yu. V., 2005, "Accounting of Molecular Viscosity at Direct 3D Numerical Simulation of Gravitational Turbulent Mixing," *VANT*, **1–2**, pp. 74–83 (in Russian).