Originally published in *Proceedings of the Fifth International Workshop on Compressible Turbulent Mixing*, ed. R. Young, J. Glimm & B. Boston. ISBN 9810229100, World Scientific (1996).

Experimental Study into the Asymptotic Stage of the Separation of the Turbulized Mixtures in Gravitationally Stable Mode

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Experimental and computational & theoretical investigations performed in the laboratories of different countries with respect to the self-similar turbulent mixing induced by Rayleigh-Taylor instability have shown that the non-dimensional rate of the turbulized mixture region growth is

$$\alpha_m = \frac{1}{2A}\frac{dL_{12}}{dS} \approx 0.07, \tag{1}$$

where L_{12} is the depth of the penetration of the light matter into the heavy one, $s = g_{11}t^2/2$ the way of the contact boundary, g_{11} the acceleration of the artificial gravitational field in gravitationally unstable mode, and A the Atwood number.

On the other hand, in Chelyabinsk-70, the computational & experimental investigations have been performed with respect to the separation of the turbulized mixtures in gravitationally stable mode [4, 5]. In these investigations, the turbulized mixture resulted from Rayleigh-Taylor instability at the unstable stage of the contact boundary movement between two fluids of different densities with density ratio $n = \rho_2/\rho_1 = 3$.

The experiments have been conducted in such a way that at a certain instant of time, $t = t^*$, the system changes from the gravitationally unstable mode to the gravitationally stable, i.e. at that instant of time acceleration $g_1(t)$ changes its sign (Fig. 1 and Fig. 2). It has been shown that the non-dimensional rate of decrease in the size of the turbulized mixture region is

$$\alpha_s = \left[\frac{1}{\sqrt{2A}}\frac{d\sqrt{L_s}}{d\sqrt{\tilde{S}}}\right]^2 \approx 0.01, \tag{2}$$

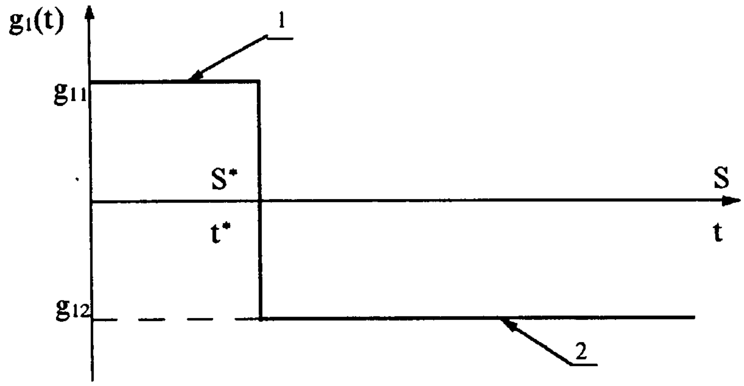


Figure 1: Dependence of artificial gravitational field generated under acceleration of an ampoule. 1. Unstable stage of motion (positive acceleration). 2. Stable stage of motion (negative acceleration).

where $\tilde{S} = \int_0^{\tau_s} d\tau \int_0^{\tau_s} g_{12} d\tau$, g_{12} is the acceleration of the artificial gravitational field in gravitationally stable mode, τ_s is the time of the separation with $\tau_s = 0$ at the instant when the mixture region has the greatest size, and $L_s \approx L_{12} \approx L_{21}$ for $n = 3$. Therefore, the separation takes place one seventh as fast the growth of the mixing region size. The value $\alpha_s \approx 0.01$ has been obtained for the initial stage of separation

$$\frac{\tilde{S}}{S^*} \leq 1.5,$$

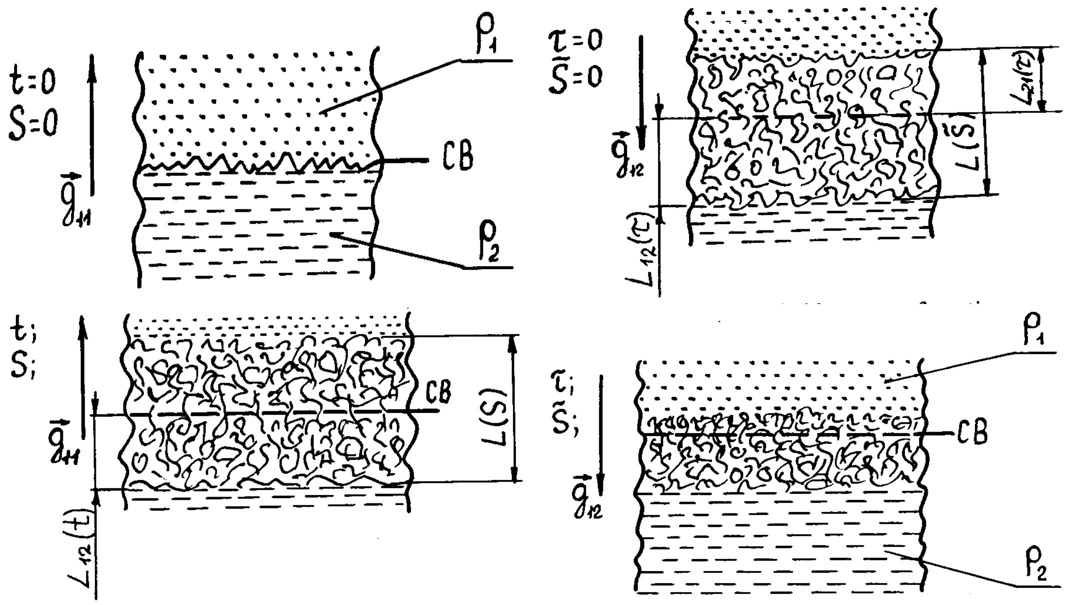
where S^* is the way of the contact boundary up to the moment t^* of the acceleration sign change.

Russian Federal Nuclear Center in Chelyabinsk-70 and Commissariat on Atomic Energy in France have made joint efforts to experimentally investigate the asymptotic stage of the separation at

$$\frac{\tilde{S}}{S^*} > 1.5.$$

To pursue this object, the installation SOM (Fig. 3) was modernized. The traditional configuration of the measuring module of the installation SOM, when the ampoule containing fluids moves in one direction from the positive acceleration channel into the negative acceleration channel, proved to be unacceptable. Thus, the scheme with the opposite ampoule motion was applied (Fig. 4).

According to this scheme, the ampoule 4 is initially placed on the membrane 5 in the channel 3. The membrane 5 separates hermetically the channel 3 from the rest of the measuring module. The compressed gas (nitrogen) is supplied to the channel 3. Under



(a) (b)

Figure 2: Scheme of turbulent mixing development of two fluids having different densities and scheme for turbulized mixture separation. (a) unstable stage of motion, (b) stable stage of motion. $\rho_2 > \rho_1$.

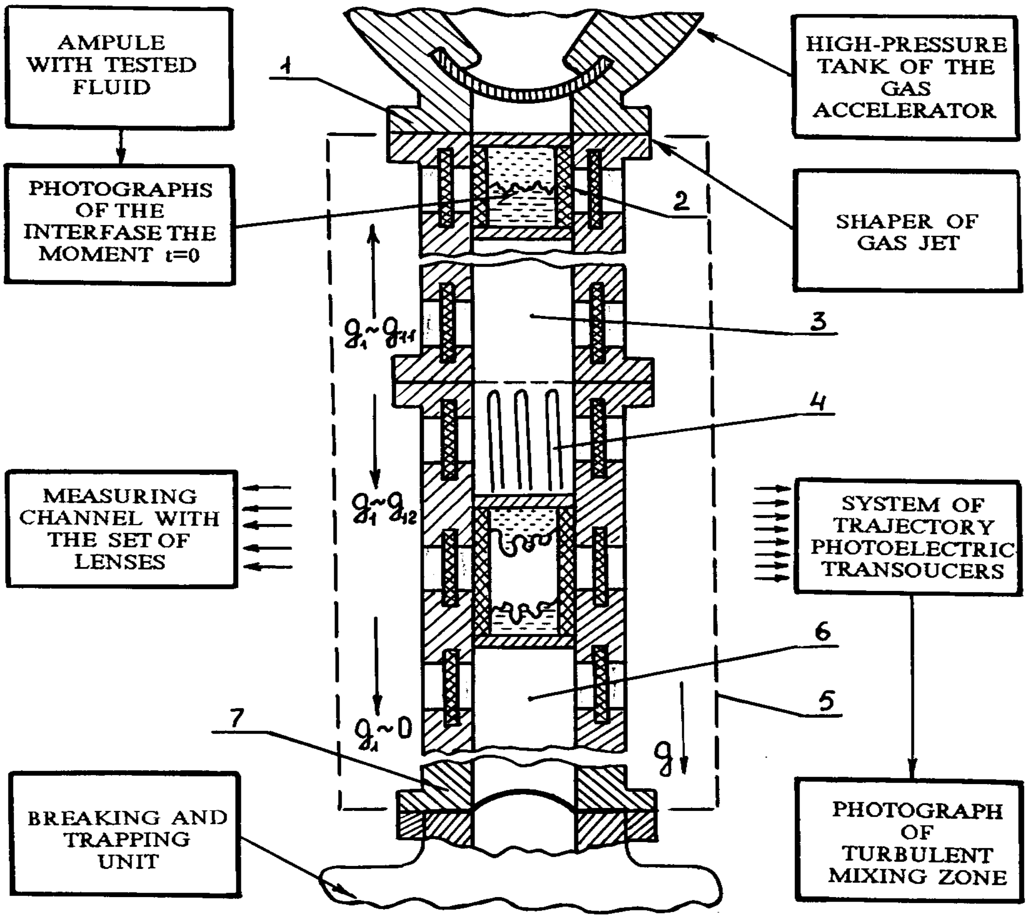


Figure 3: Functional scheme for performing experiments on the separation of turbulized mixtures by using light techniques (installation SOM). 1. Vertical gas accelerator. 2. Ampoule with investigated fluids. 3. Driver of positive acceleration (unstable stage of motion.) 4. Driver of negative acceleration (stable stage of motion). 5. Measuring module. 6. Inertial device (motion of the ampoule with zero acceleration). 7. Damping device.

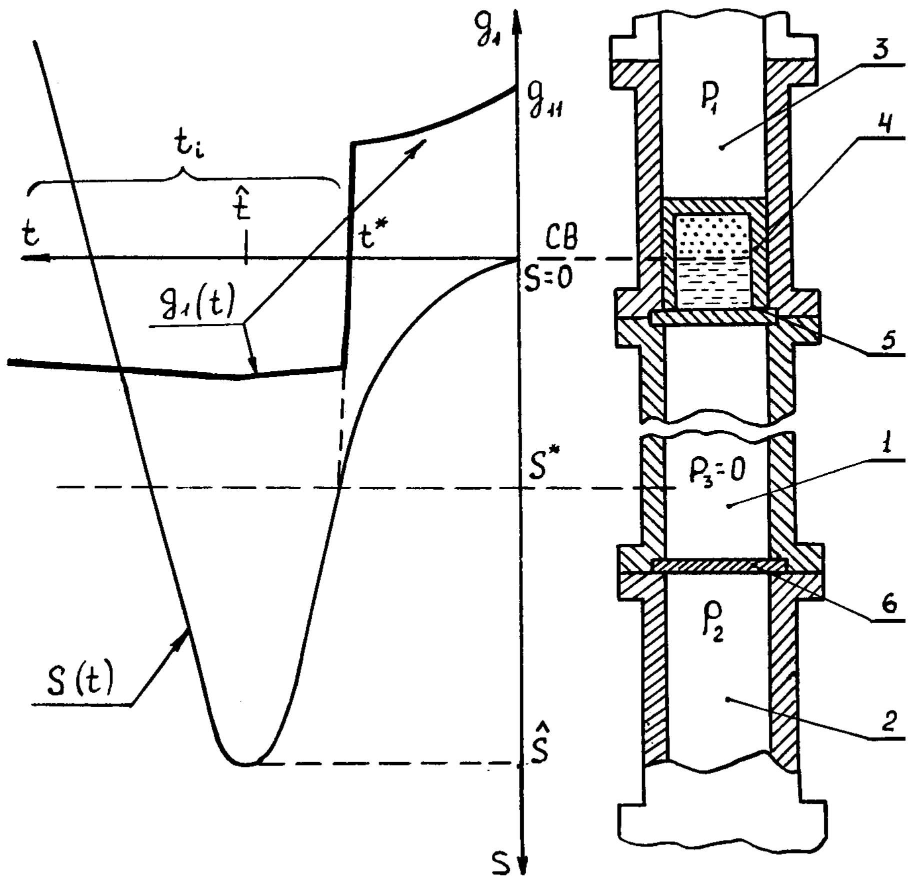


Figure 4: Physical scheme of the measuring module for forming the mode I of the ampoule acceleration. 1. Channel of positive acceleration. 2. Channel 1 of negative acceleration. 3. Channel 2 of negative acceleration. 4. Ampoule with investigated fluids. 5. Membrane I. 6. Membrane II.

gas pressure $P = P_1$, the membrane 5 is cut. In this case, the ampoule begins to move with acceleration $\vec{a}_1$ (Fig. 5) along the positive acceleration channel 1. Pressure P_3 in channel 1 is zero. The membrane 6 separates hermetically the positive acceleration channel 1 and the negative acceleration channel 2. In the negative acceleration channel there is gas under pressure P_2. When moving in the channel 1, the ampoule reaches the membrane 6 and cuts it. Beginning from this instant of time ($t = t^*$) the ampoule is moving in the channel 2 with acceleration $\vec{a}_2$. When moving in the channel 2 the ampoule reached the lowest point of its trajectory and begins to move in the opposite direction. During its opposite motion it passes successively the part of the channel 2, the channel 1, and the part of the channel 3. The negative acceleration of the ampoule during its motion in these channels will be determined by the difference in pressures $P_2 - P_1$.

During the ampoule motion with the investigated fluids along the channel of the positive acceleration, the system of two fluids will be found under conditions of the Rayleigh-Taylor instability. Beginning from the instant of time $t = t^*$, the system will be found in gravitationally stable state. At this stage, the processes of separation will be developed in the turbulized mixture region. In Fig. 4, the trajectory $S(t)$ of the contact boundary depending on time as well as the dependence of the artificial gravitational field acceleration $g_1(t)$ are given. Photo-registration of separation process by the light technique will be determined at the instant of time t_i when the ampoule is moving in the channel 2 and 3.

There were performed three groups of experiments with 5 ones in each:

1. $S^* = 36$cm, $g_{11} = 200$g, $g_{12} = 300$g,
2. $S^* = 36$cm, $g_{11} = 200$g, $g_{12} = 200$g,
3. $S^* = 13.6$cm, $g_{11} = 200$g, $g_{12} = 170$g,

where g is the gravitational field acceleration. Ampoule acceleration was directly measured by the accelerometer for every group of experiments. In each experiment one performed registration of instants of time t_i when the turbulized region was photorecorded. Coordinate L_{21} for heavy fluid penetration into the light one was determined by the photographs obtained. In every experiment we had 22 photographs of the mixing region, and 20 of them referred to the asymptotic stage of separation. Typical photo images are given in Fig. 6. Experimental data obtained were used to determine the instant of time t_s $(\tau_s = 0)$ when the mixture range at the stable stage of motion acquires the greatest size. Then parameter $\tilde{S}_t$ was defined for every instant of time τ_s. Fig. 7 gives dependencies $\sqrt{L_{21}}$ on parameter $\sqrt{\tilde{S}}$ for three groups of experiments. This figure also illustrates dependencies 1 and 2 from paper [5] obtained for the initial stage of separation. Dependence 1 corresponds to $S^* = 36$cm, and dependence 2 to $S^* = 13.6$cm.

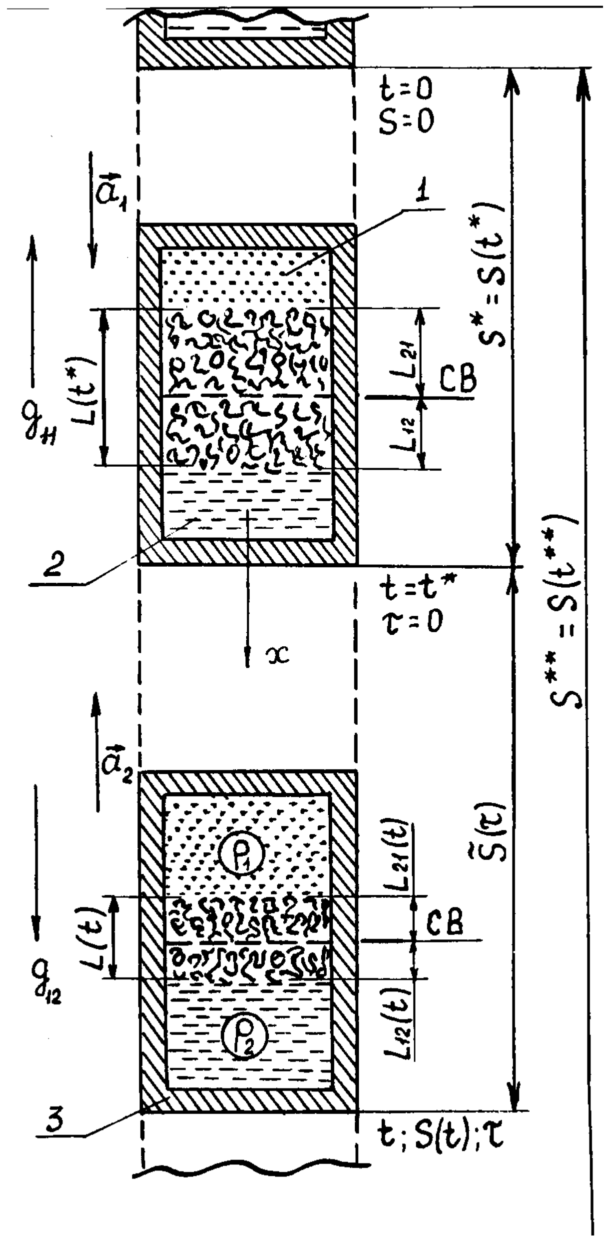


Figure 5: Scheme for separating turbulized mixtures of fluids having different densities and the basic designations. 1. Light fluid of density ρ_1. 2. Heavy fluid of density ρ_2. 3. Accelerated (decelerated) ampoule-flask.

From the position of experimental points at the asymptotic stage of separation points obtained in the first and second groups of experiments with $S^* = 36$cm lie on the continuation of dependence 1 and points obtained in the third group of experiments with $S^* = 13.6$cm lie on the continuation of dependence 2. This means that:

1. The process of separation at the asymptotic stage for the same value S^* in the given coordinates is not dependent on the ratio of accelerations g_{12}/g_{11}.

2. The process of separation at the asymptotic stage has just the same dimensionless velocity as at the initial stage.

3. Dimensionless velocity of separation is the same for various S^*.

So, this work indicates that dimensionless velocity of separation $\alpha_s \approx 0.01$ is held the same within the entire process, and turbulized mixture separation goes practically to its end.

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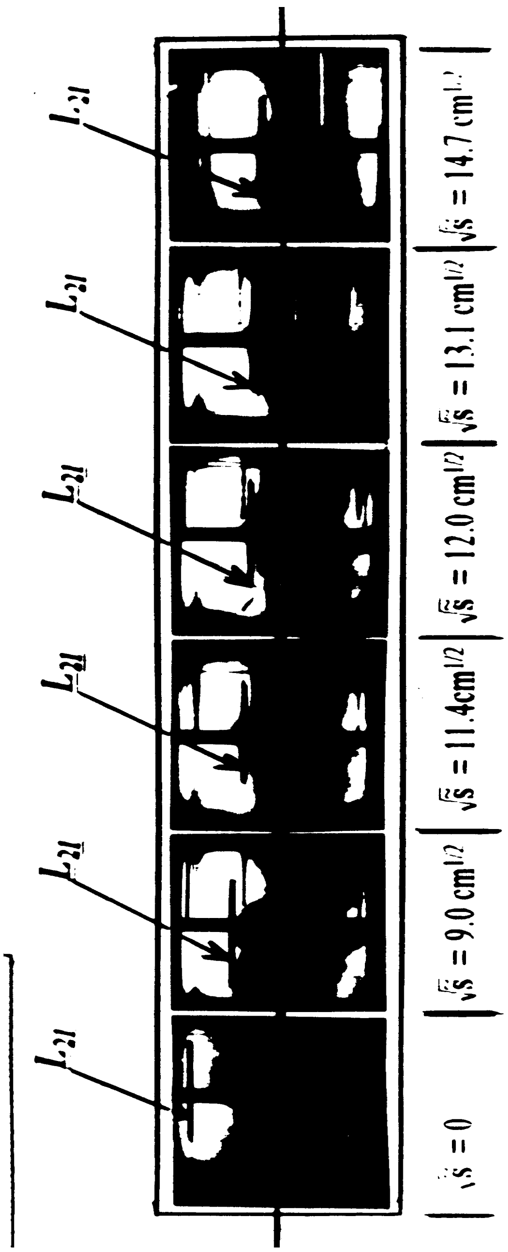

Figure 6: Characteristic images of the mixing region on the stage of separation. The initial position of the contact is indicated by the solid line seen on either end of the picture.

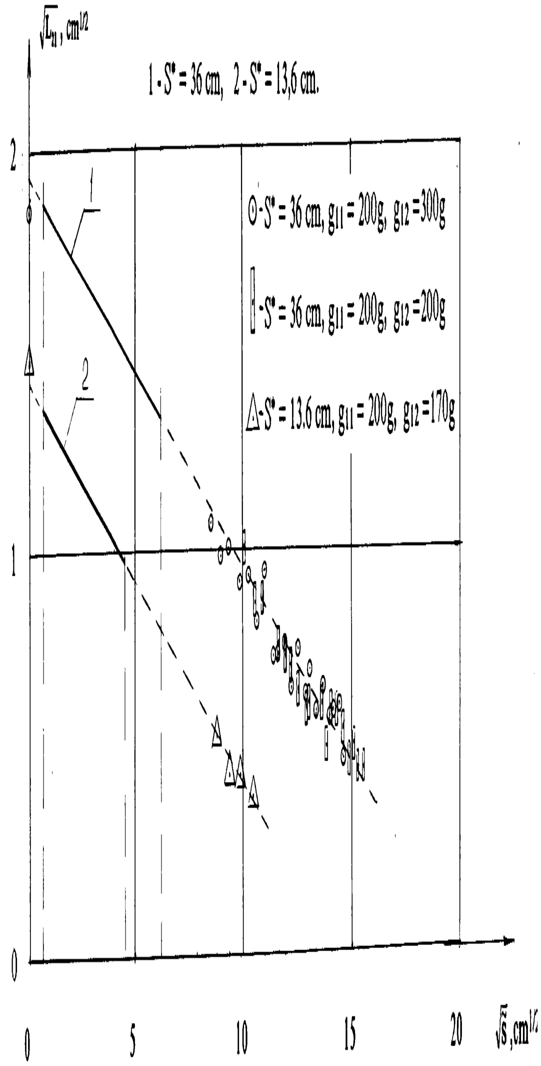

Figure 7: $\sqrt{L_{21}}$ depending on $\sqrt{\tilde{S}}$.