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EXPERIMENTAL STUDY OF THE INFLUENCE OF THE STABILIZING PROPERTIES OF TRANSITIONAL LAYERS ON THE TURBULENT MIXING EVOLUTION

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Abstract

Results of the experimental investigation of the transitional layer width influence on the evolution of the turbulent mixing induced by the Rayleigh-Taylor instability are given. In the experiments mutually soluble liquids with density ratio equal to two were used. In the region of the contact of the liquids, as a result of molecular diffusion, the transitional layer with continuous distribution of density arises. In the experiments the dependence of the delay in the turbulent mixing evolution on the size of the initial perturbations region and the characteristic thickness of the transitional layer has been determined.

Introduction

A nonstationary one-dimensional gas dynamic flow in layered systems is unstable in a number of gases. At the stages, when the lighter matter accelerates the heavy one or, vice versa, the heavy matter is decelerated on the light one, the turbulent mixing arises almost at once between them on the contact boundary. Such situations, for example, take place in highly intensive shock and explosive processes, in the problem of the laser thermonuclear fusion when compressing the targets. Taking into account these processes is especially important when compressing the special targets in the problem of the inertial thermonuclear fusion (ITF). These processes exert an immediate influence on the dynamics of targets compression. Therefore, the search for the methods of the unstable contact boundaries stabilization, even the temporal one, is urgent.

When studying the turbulent mixing evolution in the gravitationally unstable system, at the modeling installation EKAP, two possibilities were revealed to delay the mixing evolution at the unstable contact boundaries. The first possibility is associated with decreasing the initial perturbations on the contact boundary and with eliminating the reasons contributing to their occurrence. Thus, in the experiments with mercury-water, where no special measures were applied to generate small-scale perturbations, the delay in the mixing evolution was observed. The second possibility is associated with the location of the transitional layer with the continuous distribution of density on the contact boundary. In the experiments performed with some gravitationally unstable systems the period was noted during which the violation of the boundary between liquids and their mutual penetration was not observed. In the evolution of perturbations some latent period took place. E.I. Zababakhin has made his proposal that smearing the sharp boundary because of the molecular diffusion when using the mutually soluble liquids in experiments may induce the availability of the latent period. The works, in particular the work [1], in which in the linear approximation it is shown that in the systems with the continuous distribution of density the increment of the growth of the perturbations amplitude is less than in the case of the density jump at the same values of acceleration –g and the drop of densities – n, can be the basis for this. Nevertheless, this did not make it possible to determine the time of the latent period in the evolution of initial perturbations. In such systems the definite delay in the mixing evolution is observed depending on the relation of the characteristic size of the perturbations region L_o to the characteristic thickness of the transitional layer h [2,3].

Here are experimental prerequisites to state that in the system with the transitional layer it is possible to attain any delay, as one may like, in the turbulent mixing evolution, if it is necessary to create systems with $L_o/h = 0$.

In the present work the delay was determined experimentally in the gravitational turbulent mixing in the systems with the transitional layer at the relation of the heavy liquid density to that of the light one n = 2 and density perturbations in the transitional layer center.

Set-up of experiments and techniques of measurements

The study of the influence of the stabilizing properties of the transitional layers on the turbulent mixing evolution has been performed in the following set-up given in Fig.1 and Fig.2.

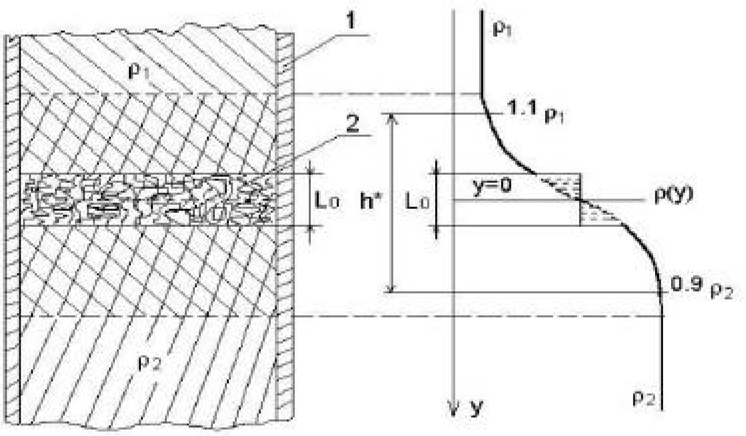


Fig.1 Physical scheme of the system being investigated

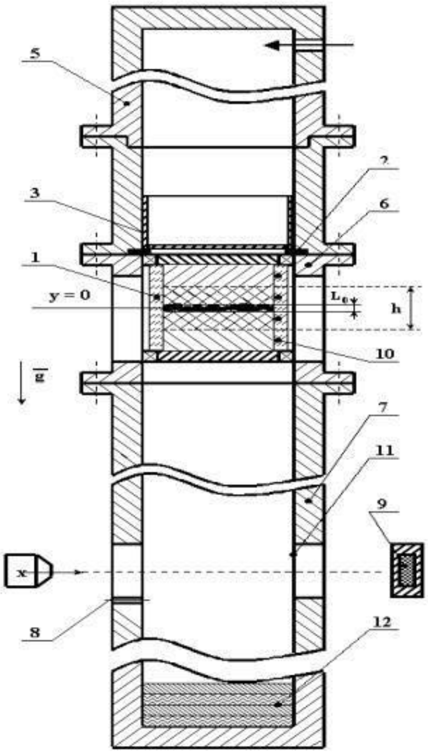
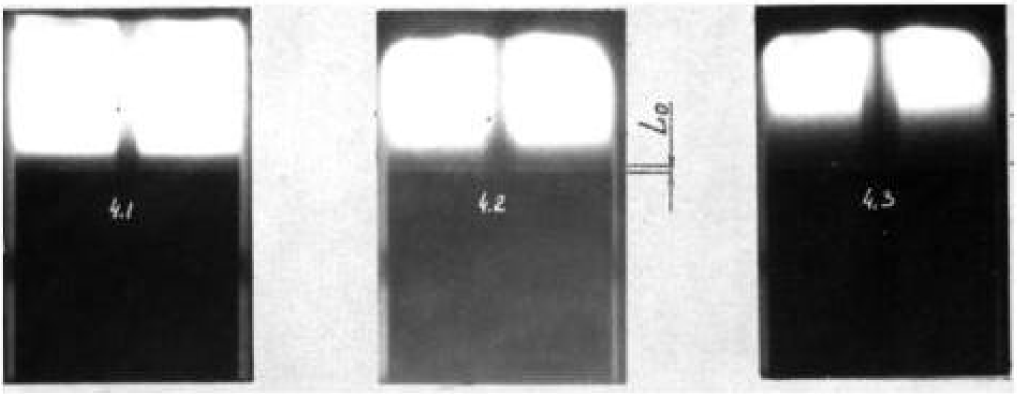


Fig .2 Scheme of the experiments set-up

The system, being investigated and consisting of two mutually soluble liquids having densities p_1 and p_2, was located into the ampoule 1, Fig.1. A transitional layer 2 with continuous distribution of density, whose density is changed according to the law placed p(y), $p_1 < p(y) < p_2$, was formed as a result of the mutual diffusion of these liquids. The transitional diffusion layer width was determined as the distance h* between the points with densities 1.1 p_1 and 0.9 p_2 . The transitional layer contains the initial perturbations zone whose size is equal to L_0 . The initial perturbation zone size L_0 can be equal to the transitional layer width as well as it can be less or larger. The investigations were carried out with artificially created initial perturbations having their size Z_B and a complex form. As a result, the perturbations were three-dimensional character and their spectrum was presented by a wide set of wavelength. The maximum of the spectrum was usually at the wavelength $\lambda \approx 1$ mm. For the spectrum maximum the relation of the perturbation amplitude to the wave length of the perturbation amounted to $\alpha/\lambda \approx 0.4$. In addition to perturbation specified by particles, in the experiments there were background perturbations induced by the no regular vibrations of the ampoule and the whole installation in the process of acceleration. Fig. 3 shows X-ray photographs of the systems with the continuous distribution of density for different h*. It is possible to see the structural elements of the ampoule 1, heavy (a dark field) and light (a light field) liquids, reference bench-marks P on the ampoule and the region of initial perturbation in the form of a light band which was formed by particle 2.

The experiments were performed as follows (Fig.2). The ampoule 1 was secured on the piston 2, which was sealed in the channel of the gas accelerator 4 by the membrane 3. By means of a high pressure system, gas was forced into the gas accelerator (GA), and when pressure in the gas accelerator channel reached the pressure equal to that of break-down (rupture) the cutting of the membrane 3 took place, and the ampoule I began to be accelerated in the measuring section 5 in the direction of the Earth's gravitational field g.



t = 45 min t = 94 min t = 280 min

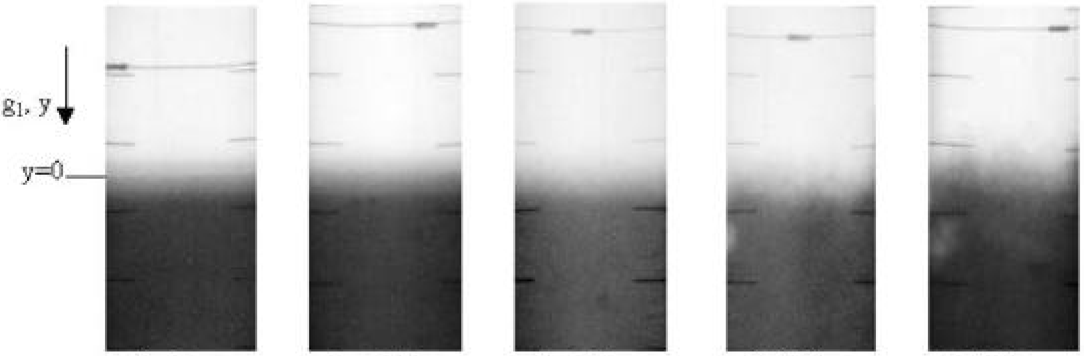
Fig.3 X-ray photographs of the systems with the continuous distribution of density for different h* (t)

When the ampoule moved the distance S, the electromechanical contact 6 was closed that led to the action of two pulsed X-ray tubes. The X-radiation of these tubes made it possible to obtain the shadow image of the definite stage in the turbulent mixing evolution on the stationary X-ray film 7. The reference bench-marks 8 on the measuring section and the bench-marks on the ampoule made it possible to determine the distance S which was passed by the ampoule by the moment of its roentgenograhpy. Then the ampoule got into the damping device 10, where its deceleration and stop took place.

Experimental results

Experiments to determine the delay in the evolution of the gravitational turbulent mixing (GTM) in the system with the transitional layer were performed on a single pair of liquids with n = 2. Two groups of experiments have been carried out. The first group of experiments had a density jump a the contact boundary (h* = 0), the second one was performed on the systems with the continuous density distribution (h* >0). Water with ρ_1 = 1g/cm^3 was used as a light liquid, Klerichi liquid with ρ_2 = 2g/cm^3 was used as a heavy one. When performing the experiments the ampoule with the square section of the working volume S = 50 x 50 mm^2 and 110 mm in length was used. The experiments were carried out at the initial acceleration 3500 g in the range of 0 < S < 1100 mm with the transitional layer of different width h* and, respectively, with the relation L0 / h*.

Fig.4 shows the characteristic X-ray photographs obtained in the experiments of the second group. It is seen that at the displacement at the distance S = 370 mm the position of initial perturbations has not changed. They occupy the same position as at the instant of time t = 0.



S = 0mm S = 367mm S = 661mm S=963mm S=1159mm

Fig. 4. Stages in the turbulent mixing evolution in the systems with the transitional layer (h^*=10.6mm, L_0=0.8mm)

On the following photos it is well seen that perturbation being evolved go out beyond the diffusion layer, and the size L of the mixing region of two liquids is growing. Hence, it follows that in the experiments the delay in the turbulent mixing is observed. We shall call the duration of this delay as time T and, respectively, the displacement $\hat{S}$ at which the failure of the transitional layer region being visible on X-ray photographs takes place. The size L_{21} depending of S is given in Fig.5 for different values of h^* (and, respectively, L_0/h^*). In the same figure the dotted line shows the dependence of the mixing front in the light liquid L_{21} (S) at h^* = 0.

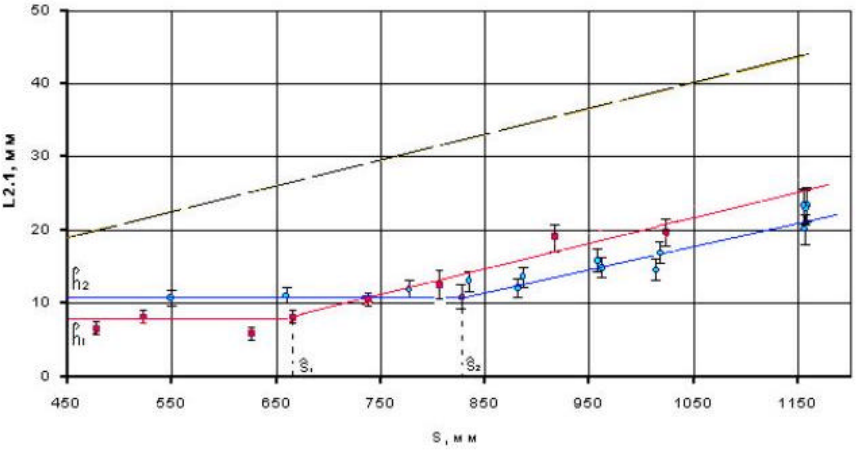


Fig.5 Dependence of the mixing front coordinate on the contact boundary displacement S

It is seen that the more h (the less L_0), the larger $\hat{S}$ and, respectively, the greater the delay T. The same conclusion is supported by the results of other series of experiments in which the relation L_0/h^* was changed within wide limits due to change in h^* as well as due to change in L_0. The results of these experiments in the no dimensional form $\hat{S}/h^* = f(L_0/h^*)$ are given in Fig.6.

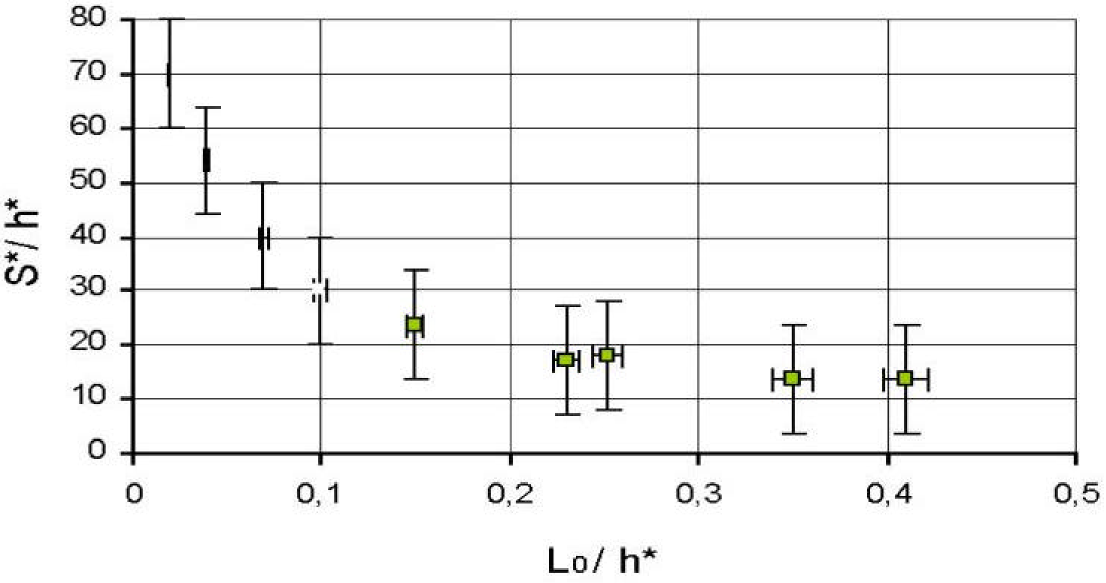
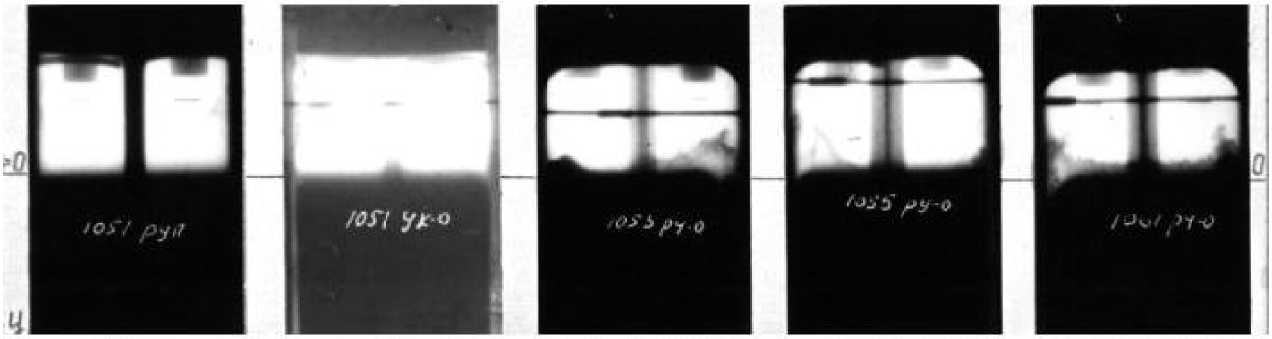


Fig.6. Dependence of the delay in the mixing evolution

From this figure it follows that the dependence $\hat{S}$/h* = f (L_0/h*) in the investigated range is L_0/h* > 0.2. However, with decreasing the initial perturbations region and with increasing the transitional layer width, the delay in the mixing evolution increases sharply. In this connection the results of experiments without particles-perturbations, i.e. with L_0 /h* = 0, are of interest. The perturbations in these experiments were only the background ones and, as was previously noted, they occur as a result of vibrations of the structural elements of the installation and the ampoule after applying the acceleration.



S = 0 S = 440mm S = 610mm S = 870mm S = 1100mm

Fig.7. Stages in the turbulent mixing development in the system with
the transitional layer at L_0/h* = 0.

In these experiments the instability evolution begins somewhat later. At the same time the instability along the ampoule walls evolves earlier. From X-ray photographs, shown in Fig.7, it is seen that the transitional layer is not involved in the turbulent motion, but along the walls the instability evolves in the form of tongues elongated along the wall. This does not make it possible to determine the exact value of $\hat{S}$.

Conclusion

1. At the installation EKAP the experimental determination of the delay in the gravitational turbulent mixing evolution has been carried out in two-layered systems with n = 2 with the available transitional layer having the continuous distribution of density. The transitional layer with the characteristic size h* was formed as a result of mutual diffusion of mutually soluble liquids.

2. Such liquids as water (ρ_1 = 1g/cm^3) and "Klerichi" liquid (ρ_2 = 2 g/cm^3) were used for performing experiments. The zone of initial perturbations with the characteristic size L_0 was formed by solid particles with their average size $z_{â}$.

Nine series of experiments differing in the relation L_0/h* (0.01 < L_0/h* < 0.6) have been carried out at the initial acceleration of 3500 g. In each series of experiments he average value of the coordinate $L_{2.1}$ of the mixing front was determined in the light liquid depending on the contact boundary displacement S. The value of the delay in the evolution of GTM was determined as a distance which was passed by the ampoule for a moment when the mixing front in the light liquid went out beyond the transitional layer size h.

3. For all the values of L_0/h* the value of the delay $\hat{S}$ in the GTM evolution has been determined. It has been shown that the less the relation L_0/h*, the greater he value of the delay. The dependence $\hat{S}$/h* = f (L_0/h*) is of nonlinear character. In experiments with L_0/h*= 0 the long-length perturbations (in the first place near the ampoule walls) develop. At the same time, the turbulent mixing in the center of the ampoule is not observed during a long interval of time.

Reference

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