Influence of Scales of Initial Perturbations on Rayleigh-Taylor Instability Growth on Gas-Liquid Interface

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Abstract: Results on the influence of scales of periodical 3D perturbations on the turbulent mix growth associated with the Rayleigh-Taylor (RT) instability evolution at the gas-liquid interface, are reported. A layer of low-strength, dissolved-in-water- gelatin was employed for modeling the liquid driven with compressed helium. The perturbations given on an obviously unstable surface were 4-hedral pyramids with a height Δ equal to the perturbation wavelength $\Delta = \lambda_0 = 0.25, 1, 2, 2.86$ mm. The results obtained in RT experiments with no initial perturbations are also presented. The width of the turbulent mix zone was found growing with increasing the perturbation scales.

Introduction

The dynamics of turbulent mix (TM) growth caused by RT instability [1] is known to be in relation with a series of parameters such as surface tension, viscosity, initial perturbations on the interface [2,3,4].

According to current recognition, viscosity and surface tension of liquid at considerable acceleration g of the layer does not practically affect the TM growth. More complex case is the relation between initial perturbations and TM growth.

Self-similar turbulence occurs, in particular, at "forgetting" the initial perturbations.

As it has been shown in theoretical-numerical work [4], the rate and how the rate goes to self-similar form depend on perturbation density within the initial transition zone. Moreover, this work has shown, that TM (TMZ) does not occur when initial perturbations are lacking.

Currently, in experimental as well as in theoretical plane there are some questions of interest: what are initial given perturbations on the interface to be further "forgotten", when it occurs, and whether they are "forgotten" in terms of the experimental data we have or for all practically significant cases.

Jelly technique [5] intended for studying non-stationary hydrodynamic flows allows us to answer partly the questions. The core of the technique is modeling a liquid layer by a low-strength gelatin dissolved in water. For example, the jellies, using gelatin dissolved in water at the concentration of C ≈ 4.4%, posses some strength (σ ≈ 0.005 MPa), and they are capable of conserving their shapes initially imposed on. When these jellies are driven by compressed gas at about 10 atm pressure, they would show behavior similar to that of incompressible liquids [5]. Any perturbation can be imposed on the surface of the jelly; further, its evolution could be recorded during dynamic experiment [6-8].

The subject matter of the paper is experimental results for the influence of the scales of 3D periodical perturbations given on unstable surface of a plane jelly driven by a compressed gas on TM evolution.

1. Experimental

Schematically, the experiment setup is shown in Fig.1. By this technique, a section of the acceleration channel of 40×40 mm sectional area, was placed on a matrix which surface had the following 3D perturbations a) of height (amplitude) $\Delta = 0.25$ mm and wavelength $\lambda_0 = 0.1$ mm, b) $\Delta = 1$ mm, $\lambda_0 = 1$ mm, c) $\Delta = 2$ mm, $\lambda_0 = 2$ mm, d) $\Delta = 2.86$ mm, $\lambda_0 = 2.86$ mm. (The perturbations had a regular shape of 4-hedral pyramid. Apex angle was directed to the jelly. Accuracy of manufacturing the perturbations using matrix was of about 0.07mm.) The section of the acceleration channel (which wall surfaces were greased thinly with vaseline) was filled with gelatin solution (C=4.4%) above which was placed a 4mm thick plywood to prevent the jelly from sagging. On soliciting, the matrix was removed, so the free surface of the jelly had perturbations being mirror images of ones imposed on the matrix. We also performed experiments with jellies without artificially given perturbations on their unstable surfaces. In this case, the jellies were manufactured in a thin transparent container (Fig.1, variant1). Unstable surfaces of such jellies had roughness with convexity ≈0.05 mm high due to vaseline. The mass of a jelly was about 47-52g.

The section with jelly was put in the acceleration channel. An end of the channel was tightly sealed with a cap, another one was closed with a 0.1mm thick millar diaphragm. The acceleration channel (on either side of the jelly) was filled with compressed helium of P = 13 atm. The diaphragm was broken with the electrical explosion of a nichrome wire glued on to it, so that the gas under the jelly would rapidly flow out to the atmosphere, and the jelly accelerated. The motion of jellies was visualized using high-speed frame filming in transmitted light.

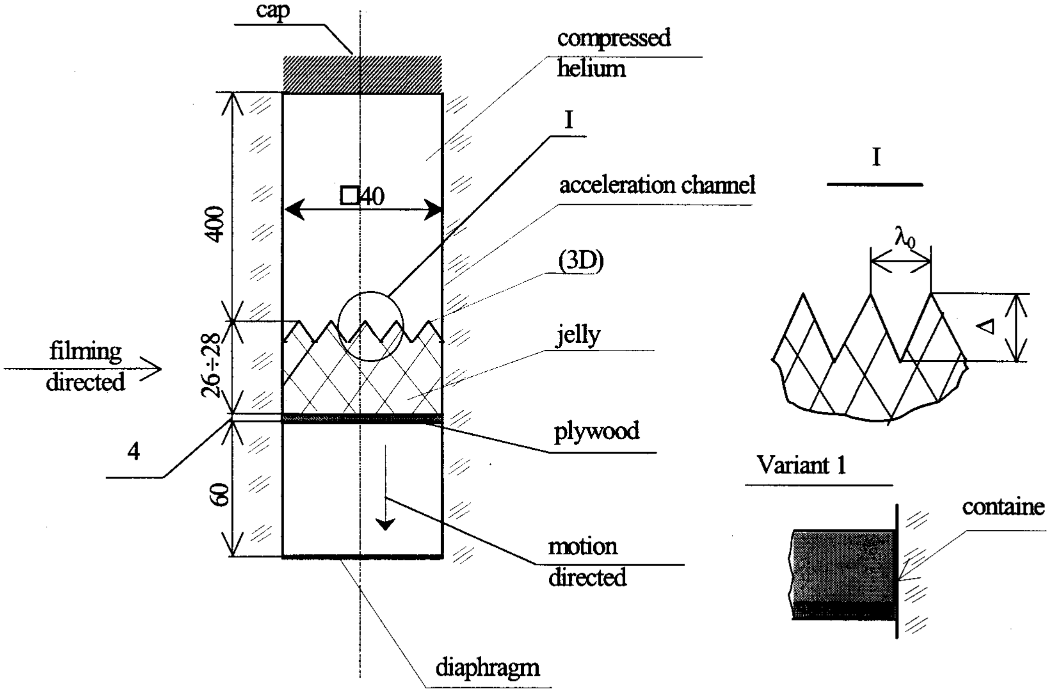

Fig.1 Schematic of the experiment setup

2.Experimental results. Analysis.

Fig.2 shows separate frames for the experiments performed with jellies without artificially given initial perturbations on their unstable surfaces and for jelly experiments with the perturbations: $\lambda_0 = \Delta = 0.25$ mm, : $\lambda_0 = \Delta = 1$ mm , $\lambda_0 = \Delta = 2$ mm, $\lambda_0 = \Delta = 2.86$ mm.

Accelerations for all the experiments were almost equal and constant ($g \approx 3 \cdot 10^4$ m/s^2).

Fig.3 presents the handling results for these experiments:

- the dependence of the averaged penetration depth (bubbles into jelly) h_{lh} on double jelly displacement S;
- the dependence of the averaged penetration depth (jelly(jets) into gas) h_{hl} on double jelly displacement S;
- the dependence of the total width of mixing zone H on double jelly displacement S ($H = h_{lh} + h_{hl}$).

At S > 20mm, the dependencies are close to be linear. The error in measuring the front h_{lh} was about ± 0.5mm. The error in measuring the front h_{hl} was estimated as ± 0.5mm for the initial stage of the TM growth and as ± 2mm for the final stage of recording. Such range is due to jet character for penetration of heavy material into a lighter – jet front is hardly processed from photos.

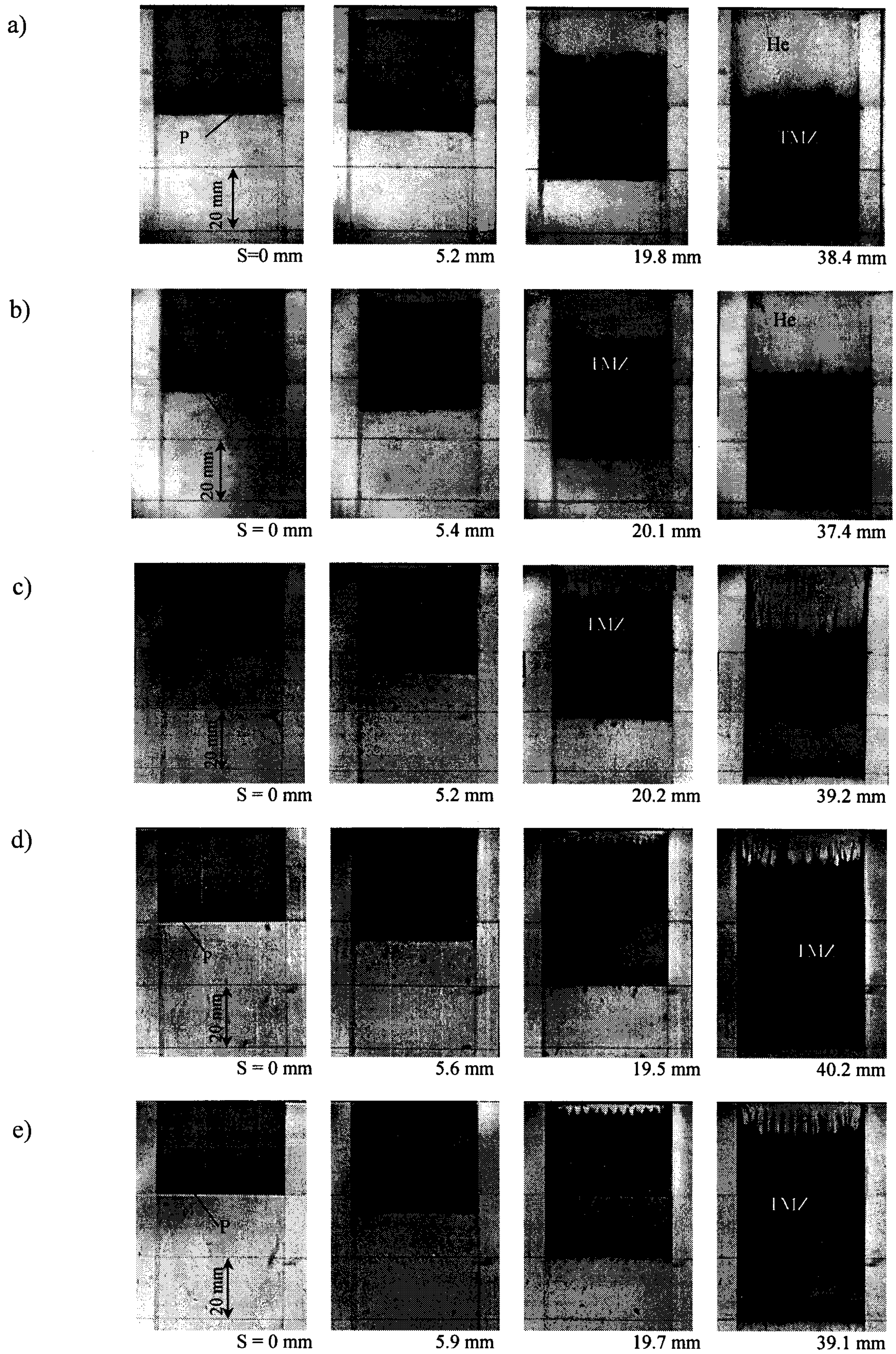

Fig.2. Frames for evolution of the TM zone on unstable surface of jellies with different initial perturbations a) without perturbations, b) $\lambda_0 = \Delta = 0.25$mm, c) $\lambda_0 = \Delta = 1$mm,d) $\lambda_0 = \Delta = 2$mm,e) $\lambda_0 = \Delta = 2.86$mm. Notations: J-jelly; He-compressed helium, TMZ-turbulent mix zone, P – plywood, S - displacement

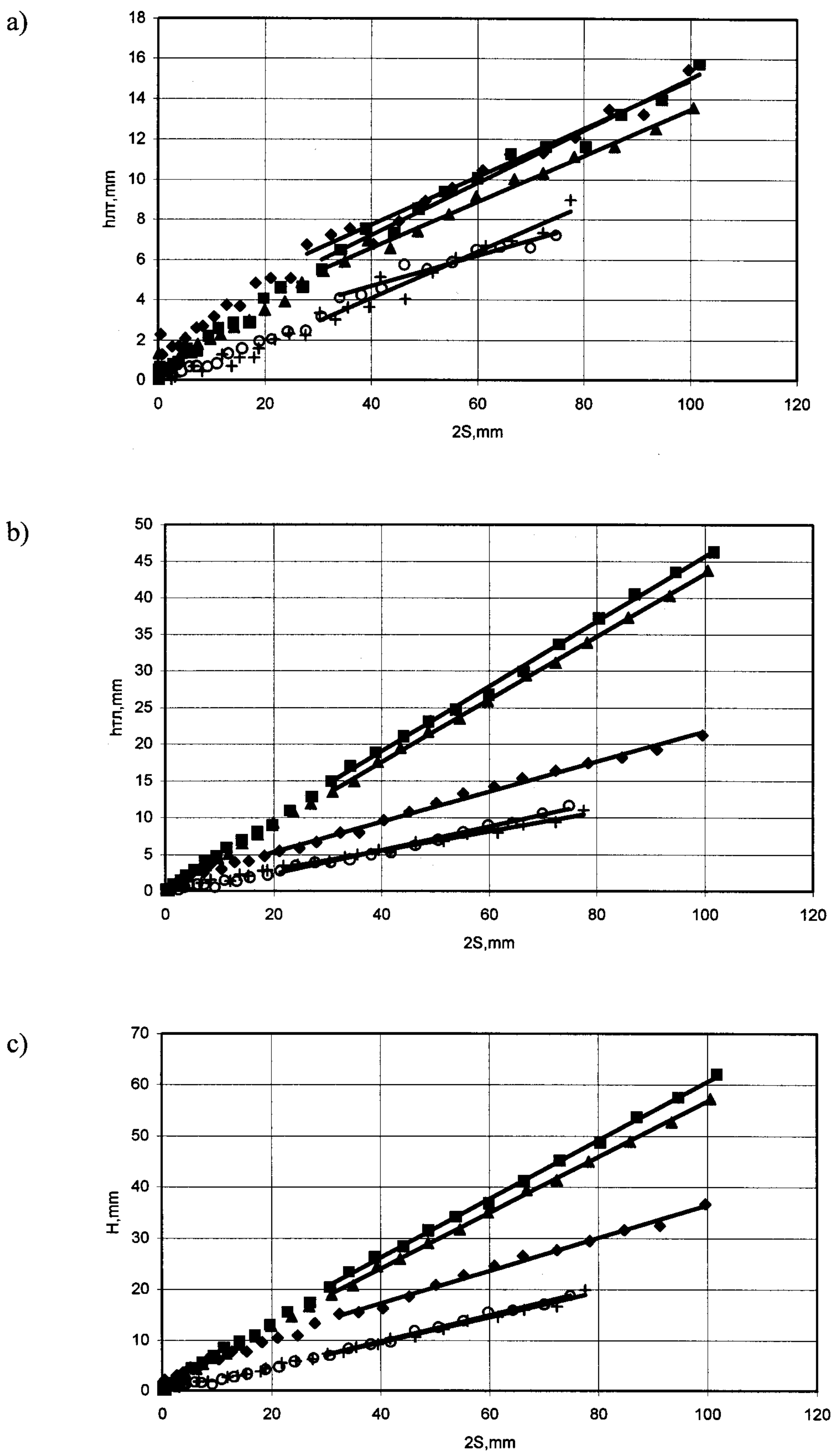

Fig.3. Processed results: a) dependence of penetration depth of gas into jelly h_{lh} versus double displacement 2S; b) dependence of penetration depth of jelly into gas h_{hl} versus double displacement 2S; dependence of total width of turbulent mix zone H versus double displacement 2S. Notations: ◆ - $\lambda_0 = \Delta$ =1mm, ▲ - $\lambda_0 = \Delta$ =2mm, ■ - $\lambda_0 = \Delta$ = 2.86mm, +-without perturbations, o- $\lambda_0 = \Delta$ = 0.25мм.

Particular attention is given for the following:

- somewhat unusual long stage of the non-linear jet growth; the perturbation amplitude increases fifteen times while the laminar flow takes place
- There is a delay in mixing at unstable interface for the jelly experiments without given initial perturbations with respect to ones with given initial perturbations.
- At $0<S\leq20$mm, the front of bubbles is more smooth for jellies with $\lambda_0 = \Delta = 1,2,2.86$ mm with respect to jellies without perturbations and with $\lambda_0 = \Delta = 0.25$mm. It may be assumed that, for this range of S and for jellies with $\lambda_0 = \Delta = 1,2,2.86$ mm, the TM growth is determined, in general, by given perturbations; i.e. random perturbations are, in some extent, suppressed.
- Intensity of the light-into-heavy penetration) β_{lh}, determined for a linear stage, is higher than the presented above dependencies; $\beta_{lh}=dh_{lh}/d(2S)$, $\beta_{lh}\approx0.12$ for jellies with $\Delta\approx0.05$mm and $\Delta\approx0.25$mm; with Δ increases from 1 to 2.86mm, β_{lh} grows from 0.1 to 0.14. However, this growth lies within measurement error which is $\delta\beta_{lh}=0.025$. So, due to low accuracy (≈20%), we can't unambiguously say about "forgetting" these perturbations for the recorded jelly displacement.
- Intensity of the heavy-into-light penetration β_{hl}, determined for a linear stage in the same manner as β_{lh}, increases from ≈0.13 to ≈0.42 (i.e. threefold) with increasing the Δ from 0.05 to 2.86. Such growth is much more than the value of errors in measuring, thus, the initial perturbations are not "forgotten" during the penetration of heavy material into a lighter (at least, for the $S \leq 50$mm).
- The total width of the TM zone H grows with the scale of initial perturbations; this growth is, in general, due to high intensity of the heavy-into-light penetration.

Conclusion

The experimental results show that the width of turbulent mix zone grows with the scale of initial, periodical 3D perturbations.

The data obtained could be used for testing numerical techniques.

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