Paper at VIII International Workshop on the Physics
of Compressible Turbulent Mixing

California Technological Institute, Pasadena, California, USA

Experimental Investigation into the Evolution of Turbulent Mixing of Gases by Using the Multifunctional Shock Tube

Yu.A.Kucherenko, O.E.Shestachenko, Yu. A. Piskunov, E.V. Sviridov,
V.M.Medvedev, A.I.Baishev

Russian Federal Nuclear Center – Academician E. I. Zababakhin
All-Russian Research Institute of Technical Physics
456770 Snezhinsk, Russia

At the initial instant of time, different density gases being investigated are found in the multifunctional shock tube and are separated by a “specter-membrane”. Then the specter-membrane is destroyed into small-scale fragments by the external force. The contact boundary of gases is accelerated by means of a compression wave, which is formed in the shock tube. At the same time, at the contact boundary of different density gases, the Rayleigh-Taylor instability arises and the unstationary zone of the gravitational turbulent mixing forms. On the basis of the experimental results the dependence of the turbulent mixing zone width on the contact boundary displacement has been constructed, and the gravitational turbulent mixing constant alpha has been determined.

1. INTRODUCTION

In most of problems associated with the fast compression processes of a matter the situation arises when a matter of less density (a light matter) and a more dense matter (a heavy matter) have a surface of their contact (a contact surface) and are moving with acceleration. In case of constant acceleration the contact surface is said to be subjected to the action of the Rayleigh-Taylor instability (RTI). If the pulsed acceleration (for example, at the passage of shock waves) takes place, then any contact surface is unstable, because the Richtmyer-Meshkov instability (RMI) arises.

The instability means that any small perturbation has a tendency to an unlimited growth, the mutual penetration of media and the destruction of structures under the action of shear turbulence take place, the turbulent mixing zone (TMZ) arises. The evolution of instabilities on the contact surface of different density media exerts an influence on the dynamics of the compression, restricts the limiting value of compression and the dynamics of subsequent processes.

The determining parameter to take into account the gravitational turbulent mixing influence is the turbulent mixing zone width which depends on the density ratio of different density media, the time of the unstable situation existence, etc. In a number of problems, taking into account the compressibility media being found along the different sides of the contact surface becomes important.

Under laboratory conditions the investigation of RTI and arising gravitational turbulent mixing (GTM) is performed with using different density liquid and gaseous media at the installations EKAP and SOM. The installation OSA makes it possible to investigate different kinds of instability (RTI, RMI) by using three replaceable drivers for these purposes. The distinctive feature of the experiments is the usage of the controlled separating membrane making it possible to form the evolution process of GTM of different gases with preset initial conditions.

The aim of the present work is to perform experiments by using the shock tube OSA creating RTI and to apply the controlled separating membrane for these investigations.

2. SET- UP OF EXPERIMENTS

For performing experiments regarding the gravitational turbulent mixing investigation the scheme presented in Fig.1 was used. The $0 < x < x_1$ region is filled up with the compressed gas and represents a high pressure chamber. From the rest of the shock tube part the chamber is separated by a light piston which is found at the point $\tilde{o} = \tilde{o}_1$. The $\tilde{o}_1 < \tilde{o} < \tilde{o}_2$ region is filled up with a light working gas **1** of density ρ_1 and represents the low pressure chamber. The $\tilde{o} > \tilde{o}_2$ region is filled up with a heavy working gas **2** of density ρ_2 and represents a measuring chamber by which the mixing process registration is carried out. In the point $\tilde{o} = \tilde{o}_2$ the separating membrane is found which prevents from the mixing of working gases during the experiment preparation. At the specified instant of time the separating membrane is destroyed into pieces of definite size by the external force. The installation operates as follows. At the instant of time $t=t_0$ the piston begins to move with constant acceleration in the positive direction of the axis X under the action of the compressed gas in the high pressure chamber. From the piston a compression wave begins to propagate in the

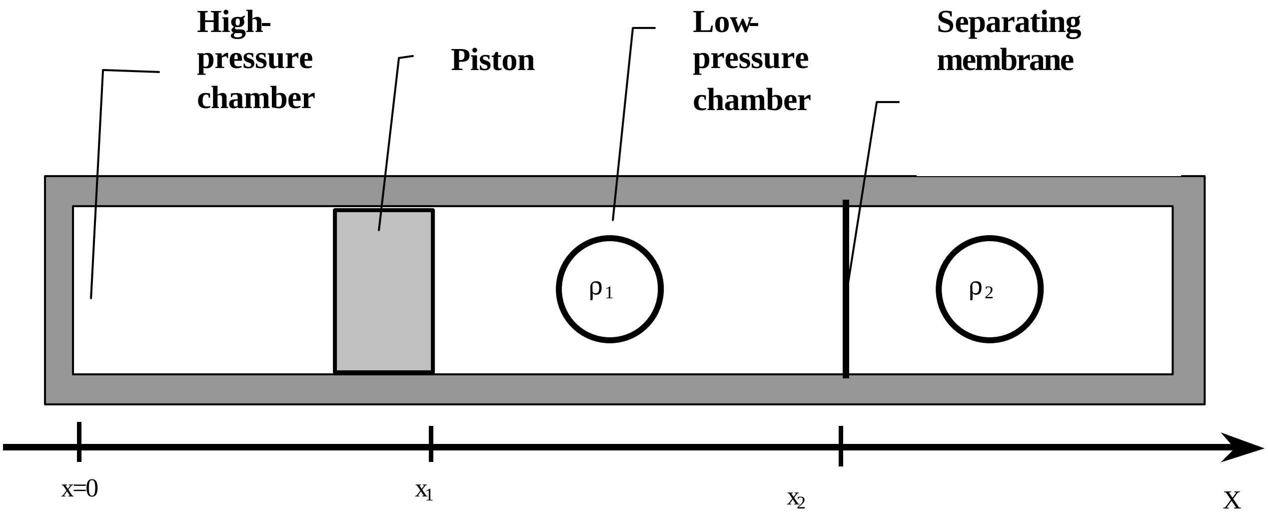

Fig. 1 Physical scheme of the experiment

positive direction of the axis X with velocity $Ñ_1$, where $Ñ_1$- sound velocity in the working gas **1**. At the instant of time $t = (x_2 – x_1)/C_1$ the compression wave arrives at the interface of gases $õ = õ_2$. At the same time, the external destructive force is applied to the separating membrane, and the contact boundary between gases begins to be accelerated. As the contact boundary acceleration profile is slightly falling and the pressure gradient in the compression wave is directed oppositely to the density gradient at the contact boundary, then the conditions are created for the RTI occurrence.

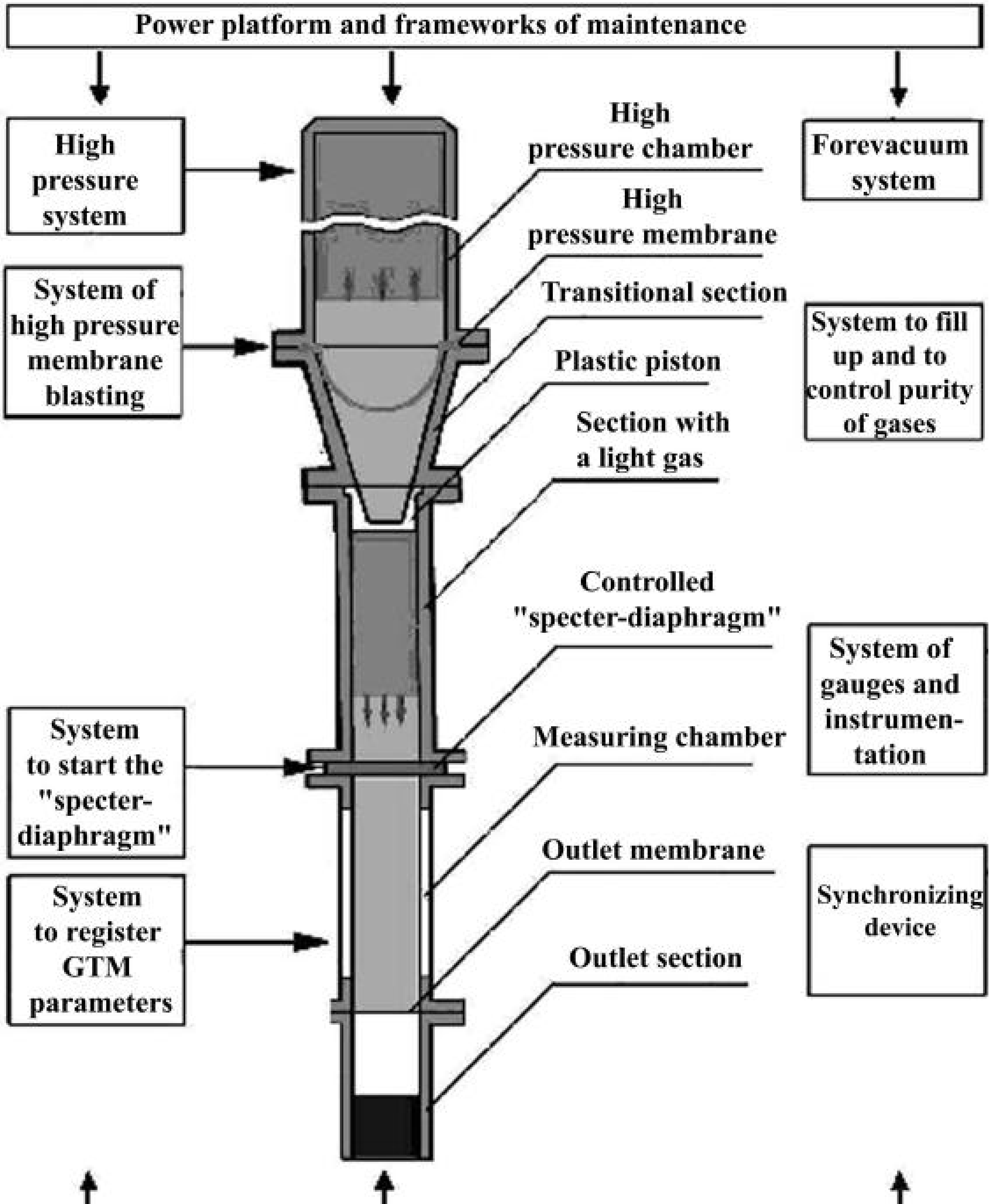

Fig.2. Functional scheme of the installation OSA

Fig.2 shows the functional scheme of the installation OSA. The total height of the installation amounts to ≈ 5 m. In the upper part of the installation the high pressure chamber is located. It represents a thick-walled vessel consisting of three parts connected among themselves by flanges. The operating pressure in the chamber is up to 2 MPa. At the upper flange of the high pressure chamber there is the emergency valve of pressure drop, pipelines for gas inlet and outlet. From the rest of the shock tube part the high pressure chamber is separated by the aluminum membrane. The membrane thickness amounts to 1 mm or 0.5 mm and determines the limiting pressure of gas in the reservoir. For the membrane destruction at the specified instant of time, a strong electric explosion is used. A sliding contact in the form of a metal needle touches the membrane in the center. The needle is connected to the positive pole of the capacitor bank by means of cables, but the membrane – to the negative pole. At the instant of time $t = t_0$ the pulse of current burns through the aluminum membrane in the center. Gas begins to flow out of the reservoir and opens the membrane completely. The gas flow passes through the conical part of the transitional section and begins to push a plastic piston. In the compression wave the pressure profile and amplitude depend on the piston mass. Under the action of the compressed gas the piston is moving with acceleration along the section with a light gas. The section with a light gas is filled up with gas of density ρ_1. The internal cross-section of the light gas section is equal to 138×138 mm^2, but the length amounts to 500 mm. The contact boundary acceleration profile depends on the light gas section. The further the contact boundary of gases from the piston is, the more the acceleration differs from the constant one and approaches to the delta-shaped one.

Prior to the experiment performing the section with a light gas is filled up with the working gas of density ρ_1 through the gas inlet system. Simultaneously, the measuring chamber is filled up with the working gas of density ρ_2 through the gas inlet system. The gas inlet system controls the extent of purity of working gases. Between the light gas section and the measuring chamber the controlled separating membrane is located. It is designed to prevent from the mixing of working gases during the experiment preparation.

The controlled measuring membrane represents the interweaved grid of microconductors, 20 μm in diameter and 4 mm in step. To this grid the liquid film of the soapy solution is applied. The film thickness amounts to ≈ 1 μm. At the specified instant of time the electric current is passed through the grid. Microconductors are heated, and the liquid film begins to be destroyed into the pieces with the typical scale $\lambda \approx 4$ mm in the places of contact with microconductors. Then the surface tension forces tighten the pieces of liquid film into small balls which act as initial perturbations at the contact boundary of working gases. When the compression wave reaches the boundary between gases, the contact boundary begins to be accelerated. As acceleration is directed from the light gas to the heavy one, the conditions are created for the gravitational turbulent mixing zone evolution.

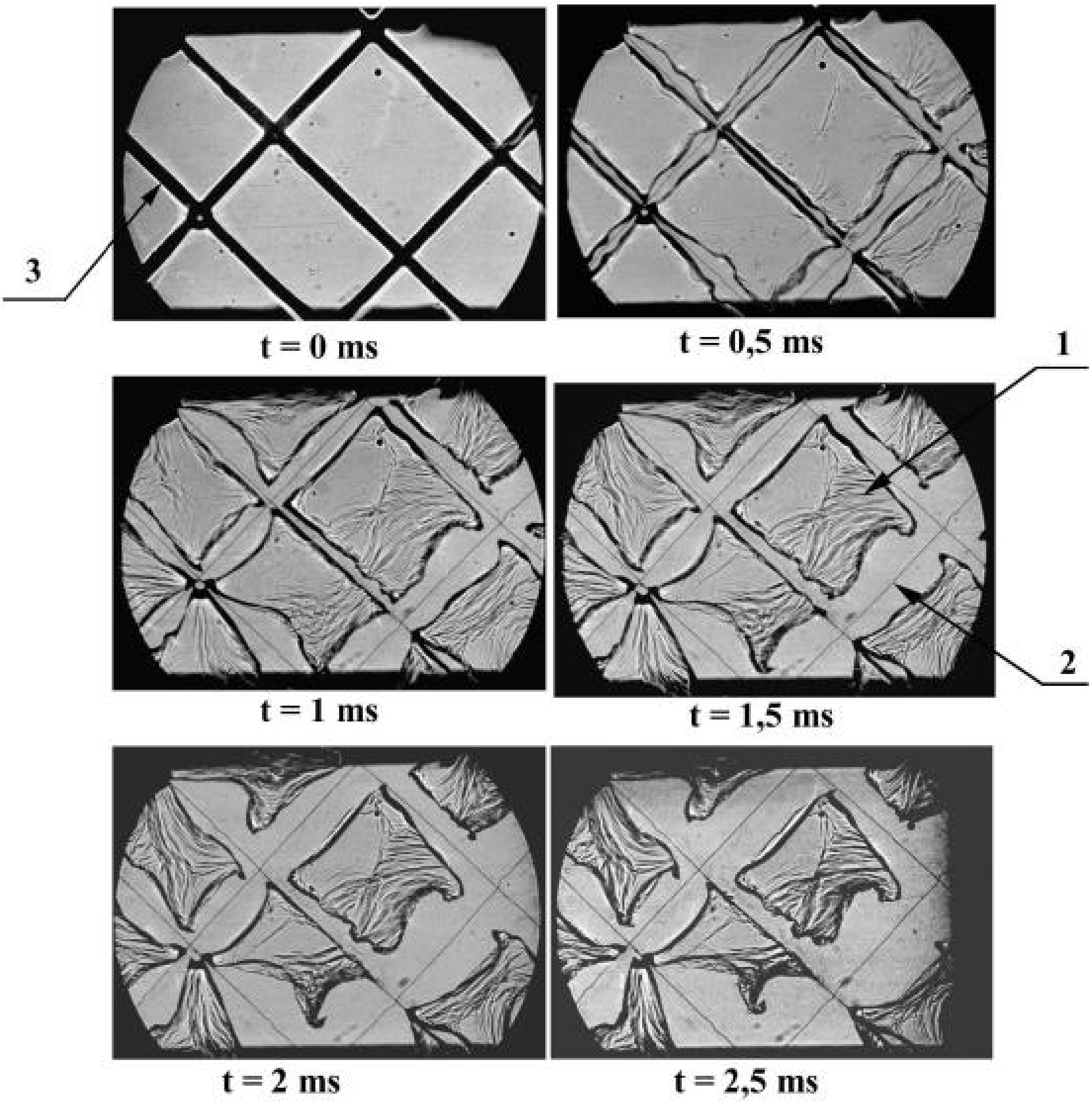

Fig. 3 Characteristic photographic images of the liquid film destruction process.

Fig.3 shows the characteristic photographic images of the separating membrane destruction process at different instants of time. In this figure microconductors are denoted by number **1**, liquid film pieces – by number **2,** the microconductor with the liquid film around it – by number **3**. From this figure it is seen that after applying the current pulse to the grid the liquid film begins to separate from microconductors and then, under the action of the surface tension forces, it is tightened into a drop.

After the block with the controlled separating membrane, the measuring section is located. It is filled with the working gas of density ρ_2. The measuring chamber has two transparent walls of high-quality optical glass. This makes possible to perform the photographic record of the turbulent mixing zone by means of a schlieren (photograph) technique. If it is necessary to investigate the late stages of the turbulent mixing process, then the additional chamber of low pressure is mounted between the block of the controlled separating membrane and the measuring section.

After the measuring chamber the low pressure chamber, 260 mm in length, is found. It is also filled up with the working gas of density ρ_2.

This chamber is necessary so that the reflected compression wave does not exert an influence on the photographic record of the turbulent mixing zone. After terminating the photographic record and passing of the piston into the low pressure chamber, it is necessary to slow down the piston. For this purpose the special outlet section is designed. When the piston passes into the low pressure chamber its velocity is $\approx 100 \div 150$ m/sec. Gas being pushed by the piston ruptures the outlet membrane which is located between the measuring chamber and the outlet section. Gas pressure before the piston becomes gradually higher than the pressure behind the piston, and the latter begins to be decelerated. When moving the piston along the outlet section the pressure of the decelerating gas increases. In order to decrease the acceleration of retardation and to prevent the reverse motion of the piston, it is necessary to release gas from the inlet section into atmosphere. For this purpose in the outlet section there are exhaust windows in which the membranes of lavsan are found. When reaching the ultimate strength the membranes are ruptured and gas gets into atmosphere. The rubber shock – absorber located at the bottom of the outlet section is designed to cancel the residual speed of the piston.

The registration of flow arising at the contact surface (CS) of two different density gases after its acceleration was carried out through the peepholes in the measuring section by the schlieren device IAB-451. The device is consistent with the high-speed camera VFU, operating in the mode of a time magnifier. Illuminating was carried out by a flash lamp. The light pulse duration was equal to 4 msec. The flash lamp, the camera VFU-1 and the phenomenon itself were synchronized is such a way that the phenomenon registration was performed at the required stage of evolution. The optical method to register transparent inhomogeneities is based on the dependence of the refractive index of gases on density.

3. Discussion of results

In the given work argon Ar (density ρ = 1.78 kg/m^3) and Kr gas (density ρ = 3.7 kg/m^3) were used as working gases. The density ratio for the given pair of gases n = 2.1, but the Atwood number $A = \frac{r_2 - r_1}{r_2 + r_1}$ for the given pair of gases was equal to À = 0.35. For these experiments the acceleration of the contact boundary of gases amounted to $g \approx 40000$ m/sec^2. The photographic record of the turbulent mixing process was carried out when changing the parameter $S = gt^2/2$ from 0.1 m to 0.5 m.

Fig. 4 shows the characteristic photographic records of the gravitational turbulent mixing process. The turbulent mixing zone is seen in photos in the form of a wide dark band. It is seen that the zone width is increased with time, but the zone itself is mixing downwards. For the correct determination of the image scale, reference bench marks are set before the measuring chamber glasses.

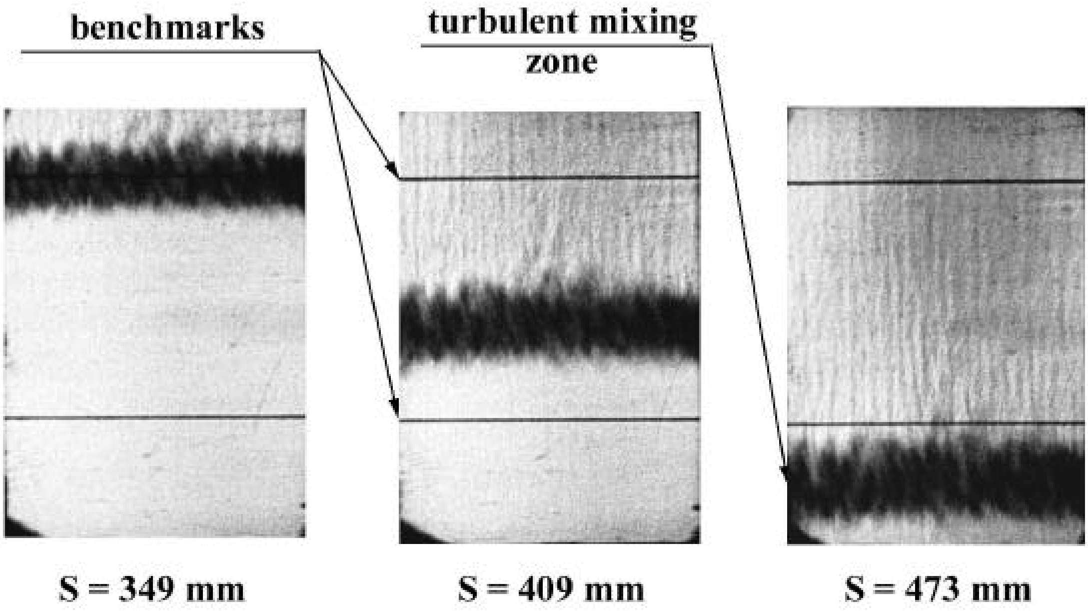

Fig. 4 Characteristic photographic images of the gravitational turbulent mixing process

Fig.5 shows the dependence of the turbulent mixing zone width on the parameter S for the pair of gases Ar – Kr. The conditions of self-similarity for the given experiment

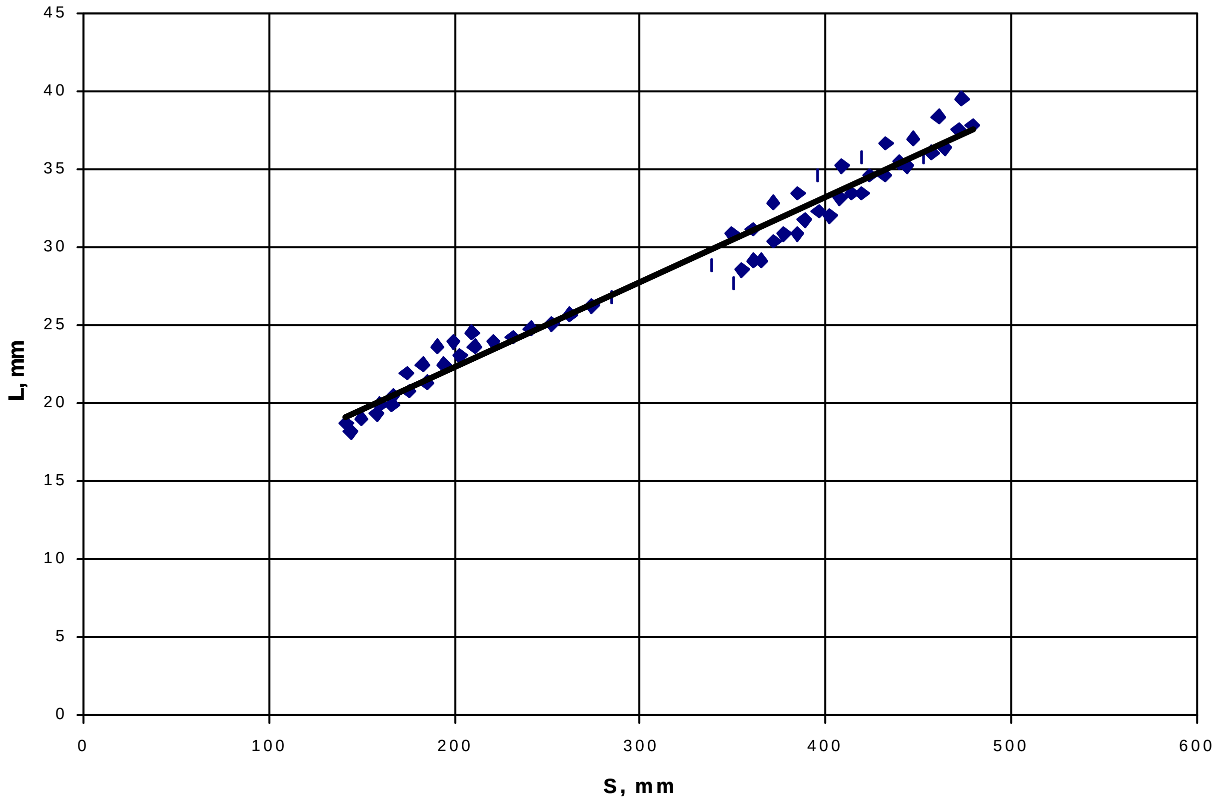

Fig.5. Dependence of the turbulent mixing zone width on the parameter S for the pair of gases Ar – Kr.

are carried out at $S \geq 100$ mm. It means that the turbulent mixing zone growth does not depend on the initial conditions on the contact boundary of gases. All the totality of experimental points at $S \geq 100$ mm can be described by the formula $L = 2\alpha AS$, where the parameter $S = gt^2/2$ is the contact boundary displacement, $A = \frac{r_2 - r_1}{r_2 + r_1}$ is Atwood number and α is the dimensionless velocity of turbulent mixing. On the basis of experimental results the constant $\alpha = 0.04$ has been determined.

4. Conclusion

In the given work the Rayleigh-Taylor instability for gaseous media was studied. Ar and Kr were used as working gases. Density ratio r_2/r_1 was taken to be equal to 2.1, but Atwood number $A=(r_1-r_2)/(r_1+r_2)$ was equal to 0.35.

At the initial instant of time, different density gases being investigated were located in the multifunctional shock tube and were separated by the controlled separating membrane. Then the separating membrane was destroyed by the external force into small – scale fragments with the typical size $\lambda \approx 4$ mm.

The contact boundary of gases was accelerated by means of a compression wave, which was generated by the piston being accelerated. The initial acceleration of the contact boundary of gases amounted to ≈ 40000 m/sec^2.

According to the results of experiments, the dependencies of the turbulent mixing zone width on the contact boundary displacement S have been constructed. The parameter S was changed from 100 mm to 500 mm. At the self-similar stage of the turbulent mixing evolution the dimensionless velocity of turbulent mixing α was determined to be equal to 0.04.