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EXPERIMENTAL INVESTIGATION INTO THE SELF-SIMILAR MODE OF MIXING OF DIFFERENT DENSITY GASES IN THE EARTH`S GRAVITATIONAL FIELD

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Abstract

At the installation OSA the experiments on the investigation of the self-similar mixing of different density gases in the Earth's gravitational field have been performed. At the same time, the light gas was found under the heavy one, and the gases were separated by a specter-diaphragm. At some instant of time the specter-diaphragm was ruptures into small-scale fragments by the external force. At the formed contact boundary of two different density gases the Rayleigh-Taylor instability and the unstationary zone of turbulent mixing evolved. For three values of Atwood number the experiments were performed. In the experiments the mixing front trajectories in the light gas and the heavy one were recorded. According to the results of experiments the mixing asymmetry coefficient and the constant α defining the nondimensional rate of mixing have been determined.

1. Introduction

In many gasdynamic phenomena such situations are widely met when a heavy medium accelerates the light one and vice versa. Depending on the acceleration profile and direction, at the contact boundary the Rayleigh-Taylor or Richtmyer-Meshkov instabilities can arise. At the same time, at the contact boundary of two different density media the unstationary mixing zone arises. The given work is devoted to the investigation of the self-similar mode of different density gases in the Earth's gravitational field.

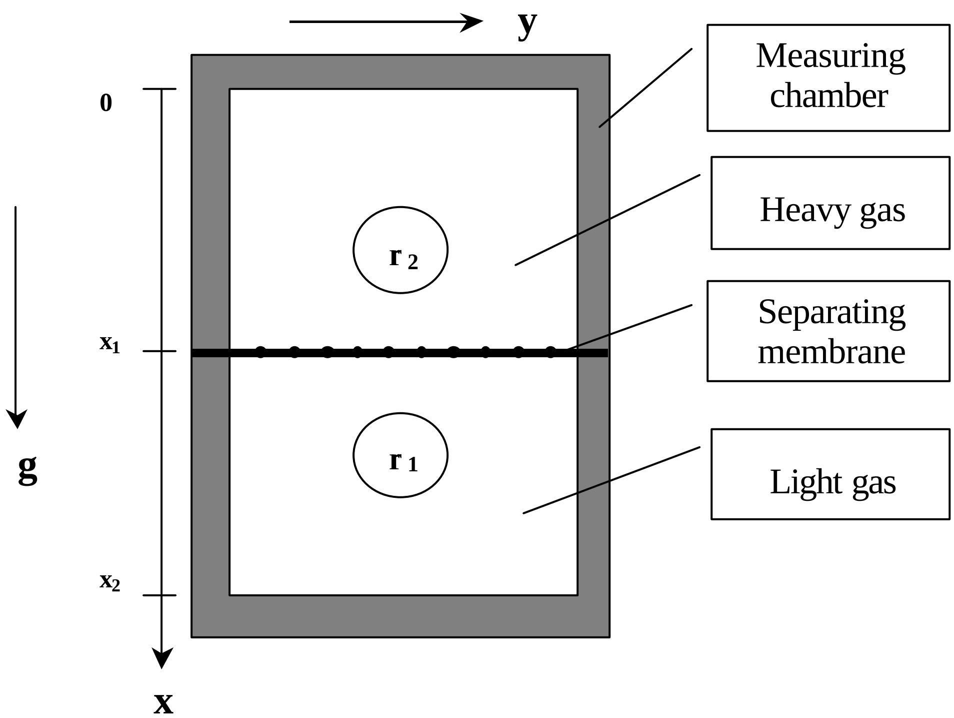

Fig.1 Physical scheme to perform an experiment measuring chamber

The physical scheme of experiments is shown in Fig.1. In the region $0 < x < x_1$ there is gas 2 of density ρ_2, and in region $x_1 < x < x_2$ there is gas 1 of density ρ_1. In the point $x = x_1$ a separating membrane is placed which prevents from mixing of working gases during the experiment preparation. At the specified instant of time the separating membrane is ruptured into fragments of definite size under the action of the external force, and different density gases begin to interact between themselves. In so far as the heavy gas ρ_2 is found under light gas ρ_1 and the Earth's gravitational acceleration is directed from the heavy gas to the light one, then at the contact boundary the Rayleigh-Taylor instabilities arises. The process of the gravitational turbulent mixing zone evolution is visualized by means of schlieren-technique and is recorded on the photographic film.

2. Set-up of experiment

In Fig.2 the functional scheme to perform experiments is shown. The gases being investigated were located in the measuring chamber with transparent walls and the internal cross-section equal to 138 x 138 mm^2. The gases are separated by the separating membrane to prevent from the interaction between themselves at the stage of the experiment preparation.

Filling up with gases was carried out by means of the gas filling system, which supported the pressure drop ΔP < 10 Pa on both sides of the separating membrane. This is necessary to provide the conservation of the separating membrane, which withstands the limiting pressure drop ΔP ≈ 40 Pa.

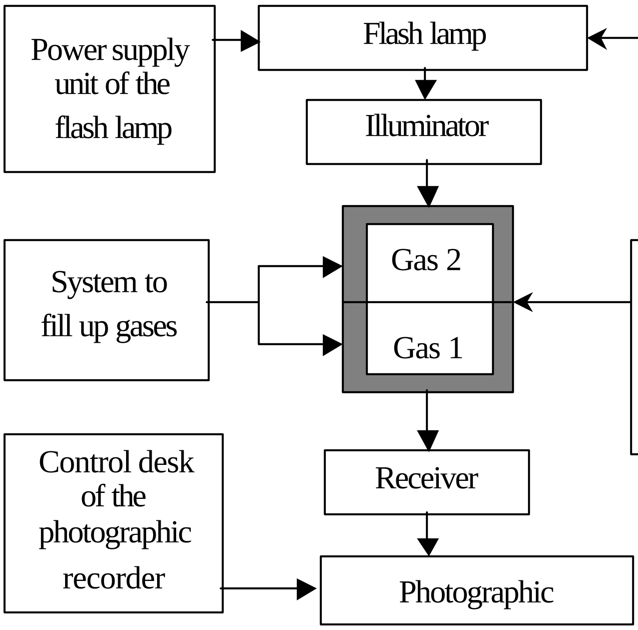

Fig 2 Functional scheme of experiments

At instant of time t= 0 an electrical pulse is applied to the grid of microconductors from the capacitor bank which is the part of the initiation system of the separating membrane (capacitor bank capacity C = 0.25 μF, voltage U = 12 kV). At the same instant of time, the flash lamp begins to operate in a stroboscopic mode illuminating the measuring chamber. Optical nonuniformities are visualized by means of the light and shade device IAB – 451. The turbulent mixing process evolution is recorded on the photographic film by means of a drum-type photographic recorder.

The distinctive features of the given scheme to perform experiments are:

- Constancy of acceleration at the contact boundary of gases. In the other experiments on gases the contact boundary acceleration is quasi-constant.
- Absence of gases compression and the gravitational turbulent mixing zone during the whole experiment. This makes possible to perform the unambiguous interpretation of the turbulent mixing zone width.
- Constancy of Atwood number on the contact boundary of gases during the whole experiment even for gases with different adiabatic indices.

- Absence of parietal flows, because the turbulent mixing zone, upon the whole, does not move relative to the measuring chamber walls.
- Absence of the turbulent mixing zone motion as the whole. This makes possible to determine the asymmetry coefficient of the gravitational turbulent mixing for gases.

Real gases are possessed of viscosity and in order that this parameter does not exert any influence on the mixing process, it is necessary to satisfy the condition $g1 \gg v^2 \cdot L^{-3}$, where g_1 – contact boundary acceleration, v – viscosity, L – turbulent mixing zone width. For such a gas as helium $v \approx 10^{-4}$ m^2/s, and if measurements are made at L > 5 mm, then for the realization of the above shown inequality it would be sufficient to reach

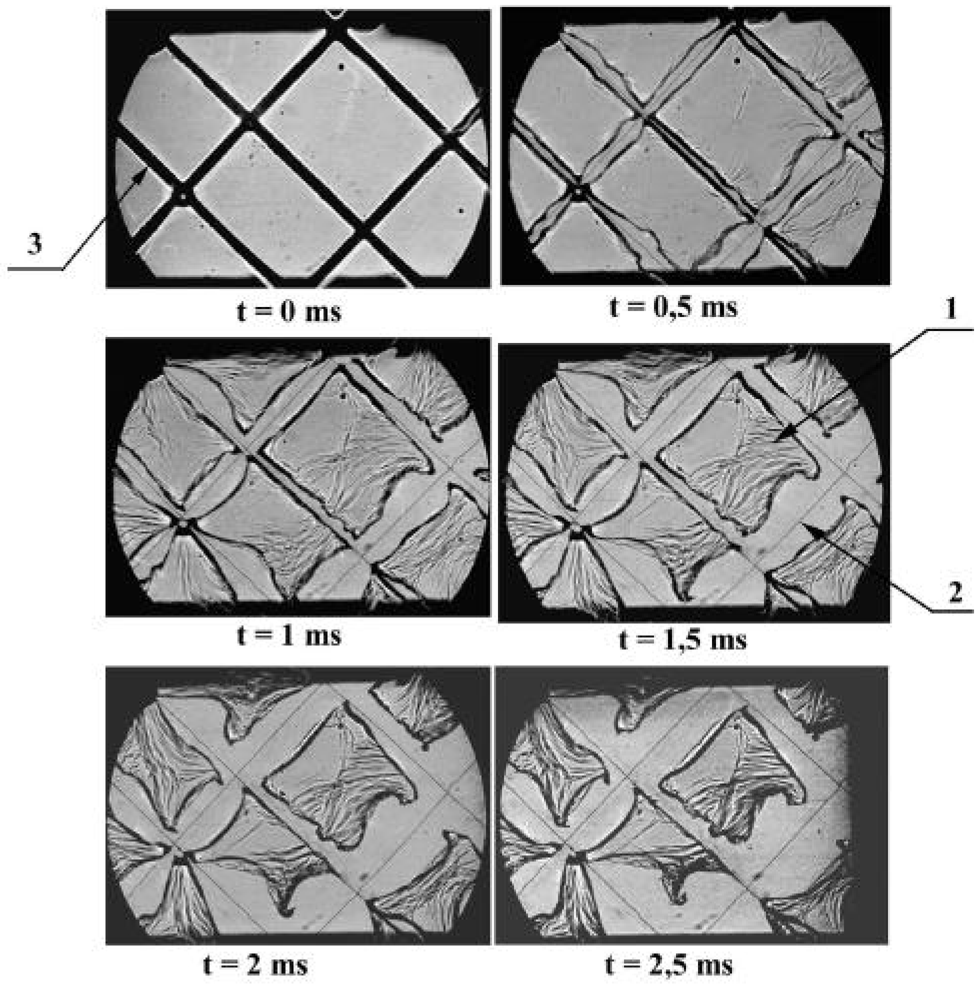

Fig.3 Characteristic photographic images of the rupture process of the liquid film.

$g_1 >> 0.09$ m/s^2. For heavier gases (air, argon, krypton) the shown inequality is satisfied at L > 1 mm and $g_1 >> 0.18$ m/s^2. Thus, viscosity of gases does not exert any influence on the gravitational turbulent mixing zone evolution at the contact boundary acceleration $g_1 = g_0$.

The separating membrane represents an interlaced grid of microconductors, 20 μm in diameter, with a 4 mm spacing. The liquid film of soap solution is applied on this grid. The film thickness is ≈ 1 μm. At the specified instant of time the electric current is conducted through the grid. Microconductors get warm and the liquid film begins to be ruptured in the places of contact with microconductors. Then the surface tension forces

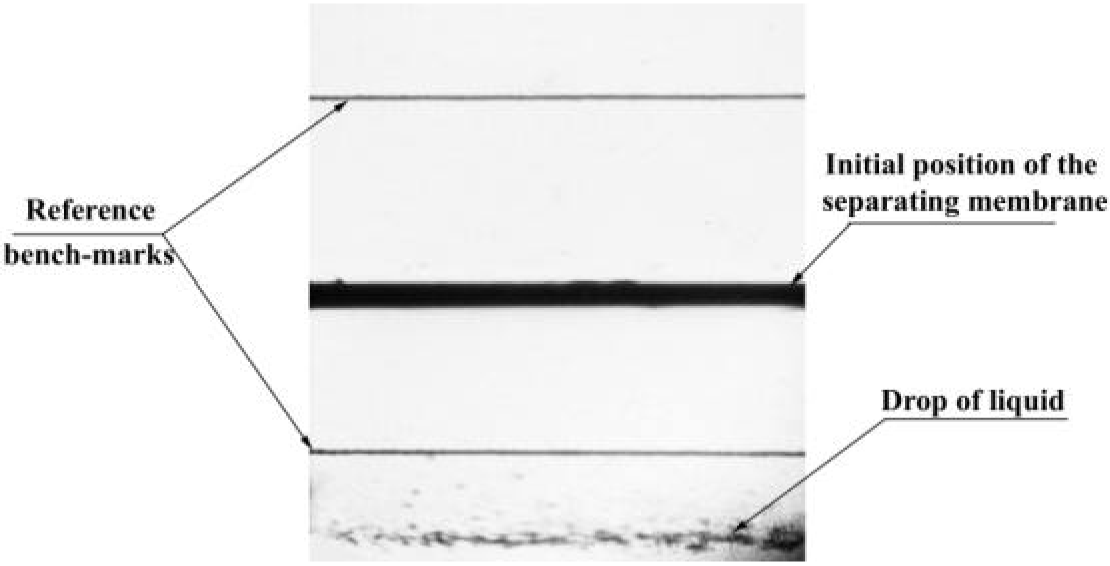

Fig.4 Characteristic photographic images of the separating membrane residues motion.

pull together the liquid film pieces into small balls which under the action of the Earth's gravitational field begins to fall down and do not take part subsequently in the turbulent mixing process.

Fig.3 shows the characteristic photographic images of the rupture process of the separating membrane for different instants of time. Microconductors are denoted by number 1, liquid film pieces – by number 2, a microconductor with a liquid film around it – by number 3. From the figure it is seen that after applying the electric current pulses to the grid the liquid film begins to be separated from the microconductor and then, under the action of surface tension forces, it is tightened into a drop.

The characteristic photographic images of the separating membrane residues (liquid drops) are shown in Fig. 4. It is seen that the drops of liquid fly in the form of a plane being parallel to that of the separating membrane. Hence, it is possible to conclude that the separating membrane rupture takes place simultaneously all over the plane.

3. Discussion of results

In the given work three groups of experiments were performed with different working gases: helium He (density ρ = 0.178 kg/m^3), argon Ar (density ρ = 1.78 kg/m^3), SF_6 gas (density ρ = 6.0 kg/m^3), krypton Kr (density ρ = 3.74 kg/m^3). In each group eight experiments have been carried out. The relation of densities and Atwood numbers for different groups are shown in Table.

Group number	Pair of gases	Relation of densities	Atwood number
1	**SF_6 – Ar**	**3,37**	**0,54**
2	**SF_6 - He**	**33,7**	**0,94**
3	**Kr - Ar**	**2,1**	**0,35**

Fig. 5 shows the characteristic photographic images of the gravitational turbulent mixing process in the Earth's gravitational field. Heavy gas is denoted by number **1**, light gas – by number **2**. Time t is counted off since the moment of applying the current pulse to the grid of

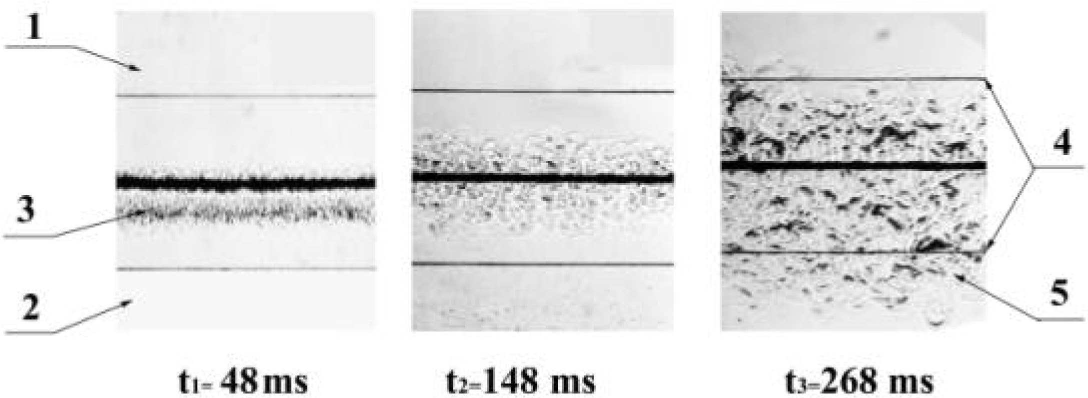

Fig. 5. The characteristic photographic images of the turbulent mixing process.

microconductors. At the first photo a number of drops **3** can be seen which fall down under the action of gravitational forces. At the following two photos the growth of the turbulent mixing zone **5** is seen. For the accurate determination of the scale and the coordinates of the mixing front the reference bench-marks **4** are set before the measuring chamber glasses.

Fig. 6a, 6b and 6c show dependencies of the mixing front coordinate of the light gas into the heavy one on the parameter S. The parameter $S = gt^2/2$, where g is acceleration of the Earth's gravitational field and t is time since the moment of the separating membrane rupture.

From the presented plots it can be seen that beginning from some value of the parameter S the mixing front coordinate L_{12} is growing according to the linear law $L_{12} = 2\,\alpha\, A\, S$, where A is Atwood number and α is constant which determines the nondimensional rate of mixing. If all the experimental points for all three groups of experiments are processed as a single set, then it is possible to obtain the value of α equal to 0.078.

According to the results of experiments the mixing asymmetry coefficient $k = L_{21} / L_{12}$. For different values of the parameter S the asymmetry coefficient is changed from 1.1 to 1.7.

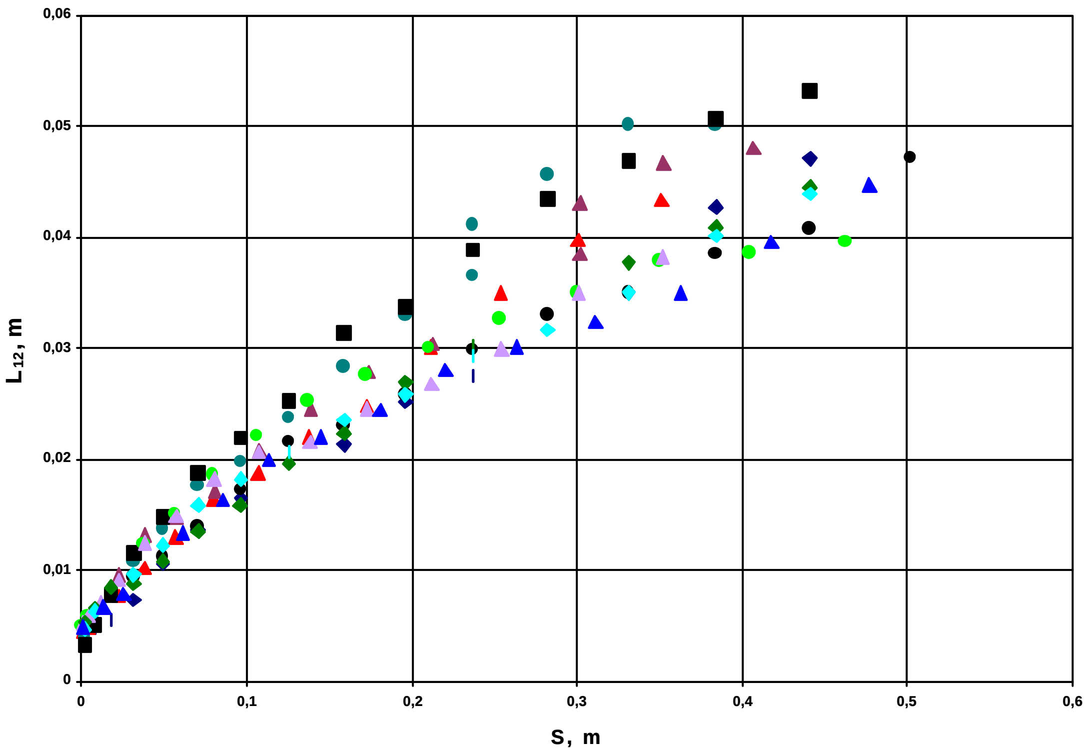

Fig. 6a Dependence of the mixing front coordinate L_{12} on the parameter S for the first group of experiments (SF_6 – Ar).

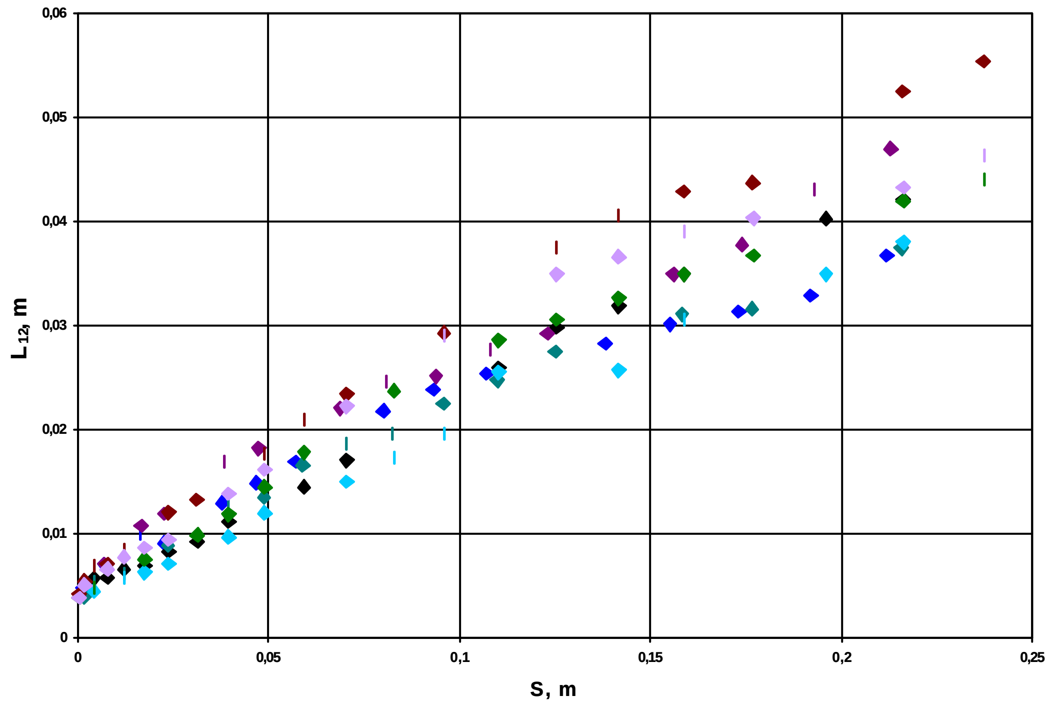

Fig. 6b Dependence of the mixing front coordinate L_{12} on the parameter S for the second group of experiments (SF_6 - He).

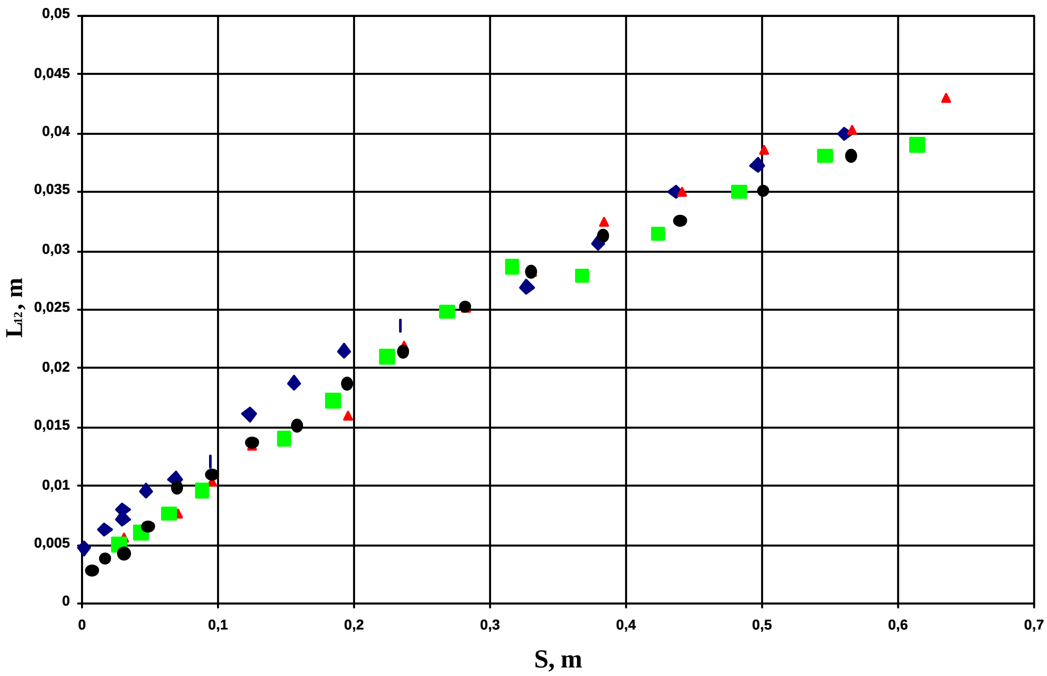

Fig. 6c Dependence of the mixing front coordinate L_{12} on the parameter S for the third group of experiments (Kr – Ar).

Conclusion

At the installation OSA the experiments have been performed with respect to the investigation of the self-similar mixing of different density gases in the Earth's gravitational field. In these experiments the controlled separating membrane of a new type with a liquid film was used. This separating membrane made it possible to carry out experiments with gases at the acceleration of the contact boundary $g_1 = g_0$. The distinctive feature of a new membrane is its low density. At the specified instant of time the membrane was ruptured under the external force action into pieces whose characteristic size $\lambda \approx 4$ mm. At the contact boundary the gravitational turbulent mixing zone growing with time was formed.

Three groups of experiments with different working gases have been performed. The density ratio and Atwood numbers for different groups of experiments are shown in Table.

Group number	Pair of gases	Density ratio	Atwood number
1	**SF_6 – Ar**	**3,37**	**0,54**
2	**SF_6 - He**	**33,7**	**0,94**
3	**Kr - Ar**	**2,1**	**0,35**

According to the results of experiments, the mixing asymmetry coefficient $k = 1.1 \div 1.7$ (for different values of the parameters S) and constant $\alpha = 0.078$ defining the nondimensional rate of mixing were determined.