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GRAVITATIONAL CONVECTION IN GAS SYSTEM Ar – N_2

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A study has been made of the "diffusion – gravitational convection" transition boundary in an argon–nitrogen binary system at different pressures and a constant temperature gradient. Research relative influence two gradients (concentration and temperature) to the density gradient. In a binary system with an unstable stratification of the density observe two mixing regimes - diffusion and convective mass transfer. It has been shown that in the case of isothermal and non-isothermal mixing, the diffusion process is stalled at one and the same pressure. The convective mass transfer becomes less intensive in the presence of a temperature gradient.

Keywords: *diffusion – gravitational convection, temperature gradient, density gradient, convective mass transfer.*

A spontaneous penetration of one substance into another is a phenomenon known as diffusion, which frequently occurs in nature and engineering, facilitating an equalization of the concentration gradient in a given volume. The rate of mixing depends on the heat motion of molecules; the smaller the molecular weight and the higher the temperature, the shorter the time of full mixing. More intensive mixing can be achieved with the convective mass transfer, which is implemented by force or by provision of special conditions for flows of matter arising due to diffusion processes.

The oceanographic investigations, which were performed in the latter half of the last century, revealed "salt fountains" [1, 2] representing water regions with a clearly marked density boundary. The laboratory studies [3, 4] demonstrated that, because of temperature and salinity gradients and a slower horizontal transport of salt as compared to the heat transfer, long narrow convective cells moving alternately up and down are formed in the bulk of the liquid. This convective motion was called "double diffusive convection" [5] or gravitational convection. Double diffusive convection appears in a liquid if two conditions are fulfilled, namely, the liquid contains two or more components with different diffusion coefficients and these components should make opposite contributions to the vertical density gradient [6, 7]. Investigations into melting of ice blocks [8] and the evolution of ice coats of ponds [9] showed that, upon exposure to solar radiation, denser freshwater remains beneath thinner seawater, flowing over some slightly sloping vertical layers formed under the mutual effect of the temperature and salinity gradients.

Studies of the thermo-effect in ternary gas mixtures revealed irregular oscillations of the temperature in the diffusion apparatus [10, 11]. Later investigations of isothermal ternary gas mixtures showed that double diffusive convection is possible not only in systems with a stable stratification of the density, but also in systems with a negative density gradient [12–15]. Studies on manifestations of the mechanical equilibrium instability in non-isothermal conditions are many fewer, and they deal with the condition of a stable stratification of the mixture density. Therefore, it seems reasonable to explore the alteration of the "non-isothermal diffusion – gravitational convection" regimes with an unstable stratification of the density in the simplest mixture, namely, a binary system. In this case, two (concentration and temperature) gradients are formed, making opposite contributions to the vertical density gradient. Therewith, conditions for the mass transfer typical of double diffusive convection are observed.

This paper reports experimental data on the processes of mixing in the Ar – N_2 binary gas system with a temperature gradient and, also, presents a theoretical analysis of the stability of the gas mixture under study.

The experiments were performed by the two flask method, which is widely used to determine diffusion coefficients in a wide range of temperatures and pressures [16, 17]. The two flask installation consisted of two basic components and thermostat, Fig. 1 [18]. One of the components was a gas preparation unit made up of a set of needle valves (1–10) for filling of the temperature-controlled flasks with initial gases from the cylinders A and B, a tank (12) equalizing the pressures in the flasks, and control pressure gages (11).

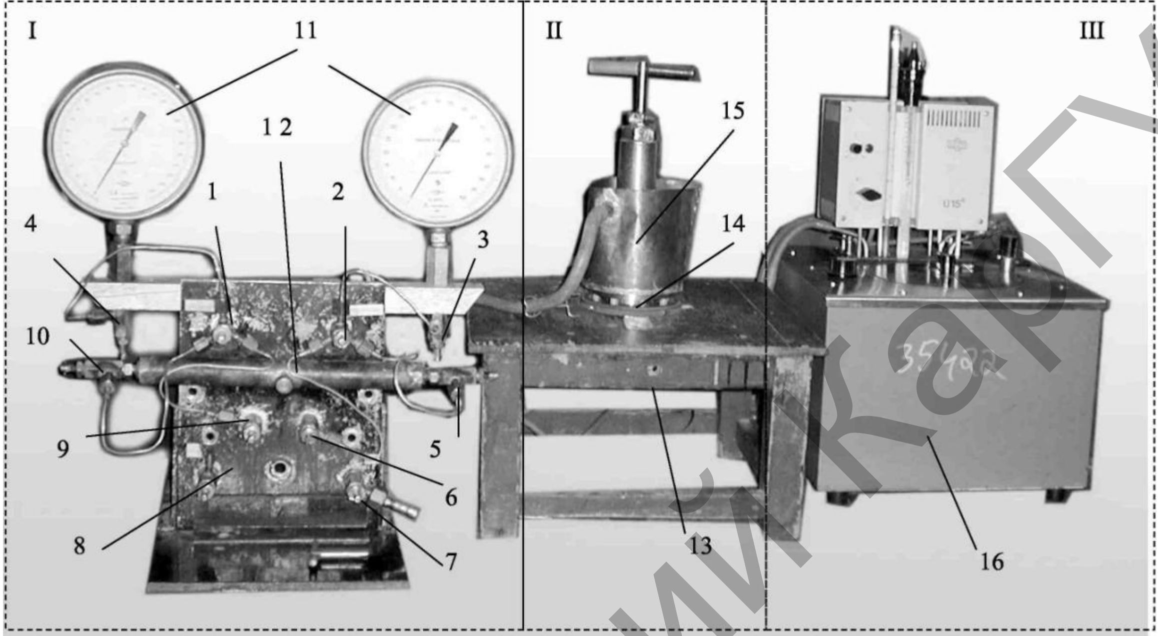

Fig. 1. Experimental arrangement. (1)-(10) valves; (11) reference pressure gages; (12) equalizing tank; (13) bottom flask; (14) diffusion capillary; (15) top flask; (16) thermostat.

The second component of the installation was the diffusion apparatus itself. It consisted of two controlled flasks (13, 15) with preset volumes V_I and V_{II} equal to $62.8 \cdot 10^{-6}$ m^3, which were connected through a capillary (14) of radius $r = 2 \cdot 10^{-3}$ m and length $l = 63.9 \cdot 10^{-3}$ m. The heavy gas Ar was placed in the top flask at a temperature of 283.0 ± 0.1 K, while the light gas N_2 was poured into the bottom flask at a temperature of 343.0 ± 0.1 K. A study with the top and bottom flasks of the diffusion apparatus held at a temperature of 295.0 ± 0.1 K was conducted for comparison.

The experimental procedure on the installation was as follows. The capillary between the flasks was stopped, one of the flasks was evacuated using a backing pump, then this flask was washed several times with the corresponding gas from the cylinder, and finally it was filled with the gas to the experimental pressure. An analogous procedure was applied to the other flask. The gas pressure in the flasks of the apparatus was read against reference pressure gages (11). The absolute experimental pressure was the sum of the atmospheric pressure, which was determined by a MBP manometer-barometer, and the excess pressure read by a reference pressure gage. As soon as the installation reached the preset temperature regime, the pressure in the flasks was equalized through a special tank (12), and the excess gas was bled to the atmosphere through a valve (7). Then the capillary (14) was opened, and the experiment start time was noted simultaneously. In a certain period of time (960 s), the apparatus flasks were isolated, and the gases were analyzed in a chromatograph. The experimental values of the concentrations were compared with the corresponding calculated values on the assumption of diffusion [19]. If the experimental and theoretical values of the concentrations coincided, non-isothermal diffusion occurred in the system. If these values were considerably different, the mass transfer was implemented as free convective flows.

The experimental data can be conveniently presented as the parameter $\alpha = \dfrac{c_{exp}}{c_{teor}}$. It is seen from Fig. 2 that, up to some pressure, the parameter α is on the order of unity. Hence, even with an unstable stratification of the mixture density, conditions for molecular diffusion can be formed in this mixture. Starting from a pressure $p \approx 0.5$ MPa, the parameter α increases linearly with growing pressure.

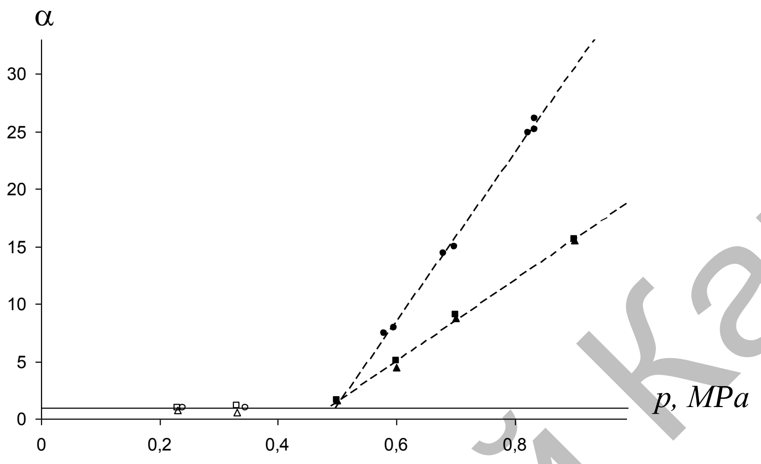

Fig. 2. Pressure dependence of the parameter α. The symbols □, ■, △, and ▲ denote the experimental data for argon and nitrogen in stable and unstable states in the case of non-isothermal mixing. The symbols ○ and ● refer to the isothermal process. The solid line corresponds to the calculations made on the assumption of diffusion.

In this situation one can suggest the presence of free convective flows, which are due to instability of the mechanical equilibrium of the mixture. It should be noted that in the case of isothermal and non-isothermal mixing, the diffusion process is stalled at one and the same pressure.

As can be seen from Fig. 2, the parameter α is larger for isothermal than non-isothermal mixing. Then the convective mass transfer is more intensive in the absence of a temperature gradient between the flasks of the diffusion apparatus. This is probably due to cross effects, diffusion, and thermal diffusion studied in [20]. One more reason is that a flow of matter, which is caused by a temperature gradient and an opposite concentration gradient, is superimposed on the total transfer. In other words, a mechanical equilibrium instability characteristic of double diffusive convection is formed.

One can see that the "molecular diffusion – gravitational convection" takes place in the case of non-isothermal mixing at a constant temperature gradient. The experimental data on mixing in the Ar – N_2 system agree with the experimental results as regards the stability boundary. A correlation of α from unity within the experimental error in the stable region (to the large and small sides for argon and nitrogen, respectively) presents a distinction from mixing in a binary system under isothermal conditions. It is probably explained by the presence of a heat flow, which acts as the "third" component.

Thus, a study has been performed aimed at determining the boundary of transition in a binary mixture with an unstable stratification of the density in the presence of a temperature gradient. It was shown experimentally that two mixing regimes—diffusion and convective mass transfer—occur in a binary system with an unstable stratification of the density. The regime is changed at a pressure p=0.5 MPa. The intensity of the convective mass transfer is higher during isothermal mixing than in the case of a temperature gradient, which is opposite to the density gradient.

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