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The Effect of Differences in the Diffusion Coefficients of Components on the Onset of Convection in Isothermal Multicomponent Systems

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Abstract. Two series of experiments on the formation of convective flows in multicomponent liquid and gaseous mixtures are considered. In the first series, the convective structures arising during the diffusion of a binary aqueous solution of salt and sugar in an aqueous solution of pure salt were studied using the schlieren method. The observed behavior of convective cells corresponds to the instability similar to the "finger structures". In the second series, the experiments were conducted to determine the effective diffusion coefficients as a function of pressure in gas mixtures 0.5504 CH_4 + 0.4496 Ar – N_2 and 0.5994 H_2 + 0.4006 Ar – N_2. Our experiments have shown that the onset of convective flows both in liquid and gaseous multicomponent mixtures is due to the difference in the interdiffusion coefficients of the components. The experimental data for the ternary gas mixtures are described in the framework of the linear theory of stability.

Introduction

Analysis of the occurrence of instability under isothermal interdiffusion showed that when the system has only one constant thermodynamic force ∇c causing convection, the description is completely analogous to conventional thermal convection (diffusion performs the role of heat conduction). If there are two forces ∇c and ∇T, qualitatively new effects arise simultaneously [1-9], which means that the convective-unstable states are also possible for a negative direction of the density gradient (a denser mixture is located at the bottom) [1,7,10,11]. These phenomena can be significantly complicated by the presence of cross-effects [2]. In this case, there are two reasons for the occurrence of thermal concentration convection: heterogeneities of both temperature and concentration. A phenomenon, which leads to the loss of stability in such systems, has been called "double-diffusive convection" [7,10-12]. Since the isothermal diffusion in ternary mixtures is also characterized by the presence of two independent partial concentration gradients, it seems important to analyse the most essential moments arising in the study of "double-diffusion convection".

A classical example is the formation of Benard cells in binary mixtures under thermal convection [1, 4, 5, 13-15]. In [16, 17], the authors determined the influence of the parameter characterizing the relationship between the diffusion coefficient and thermal conductivity in the convective flow in a continuous medium and the existence of the region of vibrational perturbation. The results of these works confirm the data from [7, 10, 18], where the occurrence of concentration convection in the diffusion of binary liquid mixture in non-isothermal conditions was studied. It has been shown that in such systems stratified density fields arise, and at the transition from one area to another temperature jumps, causing a special type of instability "finger structure", can be observed. Diffusion under certain conditions due to the presence of such areas results in the occurrence of convection.

The study of diffusion in multicomponent gas mixtures at high pressures shows that at the same conditions in some systems the process is stable, whereas in the other systems convective flows arise, which significantly affects the diffusion process. In [10,19,20] it was indicated that the instability was observed only in gas mixtures whose components differed markedly in their diffusibility.