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INVESTIGATION OF THE DIFFUSION OF TWO GASES EQUALLY DILUTED WITH DIFFERENT BALLAST GASES

Both liquid and gaseous mixes have significant significance in numerous natural and artificial processes. This elucidates the comprehensive examination of such systems in a diverse array of various applications. The presence of several processes of heat and mass transfer in gas mixtures without an interfacial boundary in the system causes the emergence of thermoconcentration gravitational fluxes, resulting in density inhomogeneity of the medium. Isothermal diffusion in helium and methane gas mixtures in a stationary medium of propane and nitrous oxide ballast gases at various pressures has been experimentally studied. It is shown that in systems where the two main gases helium and methane were diluted with propane, and then helium with propane, and methane with nitrous oxide, a repetitive unstable diffusion state of varying intensity occurs with increasing pressure. The effect of the diluent gas on the transfer of two main gases in three-component and four-component systems is significant, since the ballast gas can either accelerate, slow down, or leave the diffusion mixing process unchanged. The comparison between experimental and calculated data on the Stefan-Maxwell theory shows a noticeable difference between them.

Key words: convection, diffusion, ballast gas, multicomponent gas mixtures.

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Түрлі балласты газдармен тең сұйылтылған екі газдың диффузиясын зерттеу

Сұйық және газ тәрізді қоспалар көптеген табиғи және жасанды процестерде маңызды рөл атқаратыны белгілі. Бұл мұндай жүйелерді қолданудың кең ауқымында жан - жақты зерттеуге мүмкіндік береді. Жүйеде фазааралық шекарасы жоқ газ қоспаларында бірнеше жылу және масса алмасу процестерінің болуы жылу концентрациясының гравитациялық ағындарының пайда болуына әкеледі, және де бұл ортаның тығыздығының біртексіздігіне әкеледі. Гелий мен метанның газ қоспаларындағы изотермиялық диффузия пропан мен азот оксидінің балласт газдарының әр түрлі қысымдағы қозғалмайтын ортасында эксперименталды түрде зерттелді. Бұл жұмыста екі негізгі газ гелий мен метанды пропанмен, содан кейін гелий пропанмен және метанды азот оксидімен сұйылтқан жүйелерде қысымның жоғарылауымен әртүрлі қарқындылықтағы қайталанатын тұрақсыз диффузиялық күй пайда болатыны көрсетілген. Балласт газдың үш компонентті және төрт компонентті жүйелердегі екі негізгі газдың тасымалдануына әсері айтарлықтай, өйткені балласт газы диффузиялық араластыру процесін жылдамдатуы немесе баяулатуы немесе өзгеріссіз қалдыруы мүмкіндігі туралы айтылған. Сондай-ақ, Стефан-Максвелл теориясы бойынша тәжірибелі және есептелген деректерді салыстыру олардың арасындағы айтарлықтай айырмашылықты көрсетеді.

Түйін сөздер: конвекция, диффузия, балласт газы, көпкомпонентті газдар қоспасы.

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Исследование диффузии двух газов, в равной степени разбавленных различными балластными газами

Как жидкие, так и газообразные смеси играют важную роль во многих естественных и искусственных процессах. Это дает возможность всесторонне изучить такие системы в широком спектре применений. Наличие нескольких процессов тепло- и массообмена в газовых смесях без межфазной границы в системе приводит к возникновению термоконцентрационных гравитационных потоков, приводящих к неоднородности плотности среды. В данной работе экспериментально изучена изотермическая диффузия в газовых смесях гелий и метан в неподвижной среде балластных газов пропана и закиси азота при различных давлениях. Показано, что в системах, где два основных газа гелий и метан разбавлялись пропаном, а затем гелий - пропаном, а метан - закисью азота, с повышением давления возникает повторяющееся неустойчивое диффузионное состояние различной интенсивности. Влияние газа-разбавителя на перенос двух основных газов в трехкомпонентной и четырехкомпонентной системах существенно, так как балластный газ может или ускорить, или замедлить, или оставить без изменения диффузионный процесс смешения. Проведенное сравнение между опытными и расчетными данными по теории Стефана-Максвелла показывает заметное отличие между ними.

Ключевые слова: конвекция, диффузия, балластный газ, многокомпонентная газовая смесь.

Introduction

In the study of multi-component diffusion in gases, the occurrence of structured convective flows in certain conditions was discovered, the imposition of which on the proper molecular transfer leads to diffusion instability, i.e. mechanical imbalance of the mixture. The manifestation of this instability in the diffusion process was first observed in the study of the thermal effect in three-component gas mixtures in the Loshmidt diffusion apparatus [1]. Further studies of the diffusion process in isothermal multi-component gas mixtures at elevated pressures in a double-collar apparatus also showed a molecular transfer disorder and the appearance of powerful convective flows significantly exceeding diffusion [2, 3]. The appearance of convective flows in a closed device, such as a two-collar apparatus, could be explained by the manifestation of "Tour effects" or the influence of hydrodynamic flow, due to the diffusion bar effect, was not productive [4]. The causes of convection, or more precisely of free gravitational concentration convexity, could be explained within the framework of the linear theory of stability, allowing to identify types of mixing of gases [5, 6].

In solving practical problems in multi-component mass transport, the so-called ballast gas method is often used to diffuse several gases through a diluent gas layer. This method is preferable because the diffusion instruments and the procedure of experimentation remain the same as in the measurement of conventional diffusion coefficients [7]. If by its diffusion properties the ballast gas is close to one of the main ones, then in mutual diffusion the dilution gas plays the role of the movement indicator of the entire mixture, which allows to measure the resulting hydrodynamic flow. In the ballast gas method, the two main diffusing gases are diluted by the third, through which the mass transfer is carried. And ballast gas as an indicator allows to describe the features of the diffusion process. An experimental study of gas mixtures with ballast gas showed that, by choosing the diluent gas appropriately, the diffusion mass transfer of the main components could be accelerated, slowed down, or kept unchanged [9-11]. Thus, the results of the experimental study of diffusion in ballast gas systems suggest that the effect of the diluent gas on the transfer of the two main ones is significant.

Further study of the concentration convection caused by mechanical imbalance with ballast gas showed that increased pressure affects the occurrence of the area of stable diffusion and unstable convective mixing. Moreover, the direction of the ballast gas flow depended on the pressure [12-13].

In connection with the above, the focus of this paper is on the experimental study of the diffusion of two gases equally diluted by different ballast gases at different pressures. Diffusion in a mixture of helium-propane gases in a fixed medium of ballast gas (dilution gas) was studied. Initially, both the main diffusing gases of helium (top cylinder) and methane (bottom cylinder) were diluted with propane, and then with propane and nitrogen oxide, i.e. two systems were studied:

1) $0.570He + 0.430C_3H_8 - 0.580CH_4 + 0.420C_3H_8$

and

2) $0.575He + 0.426N_2O - 0.425C_3H_8 + 0.574CH_4$.

Method

This article presents the results of the study of the dependency of the concentration of diffused propane on the pressure. The experiments were conducted using the two-collar method [6-8]. The volume of the appliance was the same and amounted to 62.0 cm^3. The length and diameter of the diffusion channel were 63.1 mm and 4.0 mm, respectively. The duration of all experiments at 298.0 K was 1 hour.

The experiments were carried out in the range of pressures from p = 0.4 MPa up to p = 1.2 MPa.

Results and Discussion

Figure 1 shows the change in the concentration of the ballast gas - propane in the upper cylinder of the diffusion apparatus depending on the test pressure for the system

$$0.570He + 0.430C_3H_8 - 0.580CH_4 + 0.420C_3H_8$$

(system 1). Here are the results of the calculations of the concentration of propane from pressure according to the Stefan-Maxwell equations (point line). The calculations were made with a pressure range of 0.2 MPa.

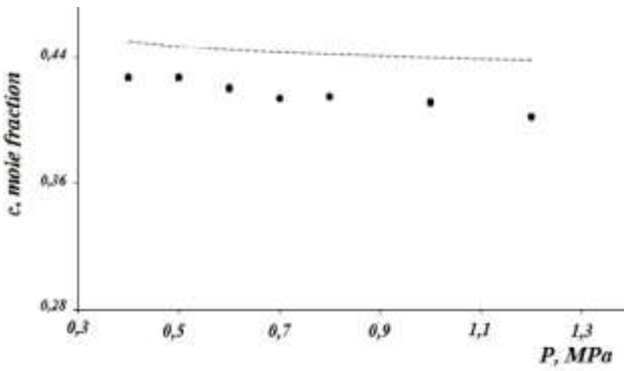

Figure 1 – Change of the concentration C_3H_8 in the $0.570He + 0.430C_3H_8 - 0.580CH_4 + 0.420C_3H_8$ system's upper cylinder depending on the pressure (points are the results of the experiment, a pointed line is the theoretical calculation)

As you can see from this figure, in system 1, during the diffusion mixing process, the concentration of propane in the lower cylinder increased by 0.054 moles (the initial concentrations of propane in the bottom and upper cylinders were equal) when the pressure increased to p = 0.5 MPa. Further pressure increases leads to a decrease in the concentration of propane in the lower cylinder and at pressure p = 0.7 MPa reaches a minimum. To 0.8 MPa there is again a slight but noticeable increase in the ballast gas concentration, which then decreases to p = 1.2 MPa. Thus, in the pressure range of 0.4 to 1.2 MPa, there is a recurring unstable diffusion state of varying intensities, i.e. the transfer of the diluent gas from one bubble to another with subsequent return to the first. This feature found in ballast gas systems indicates that the diluent gas is circulating through the diffusion channel.

For the quantitative study of the circulation of the diluent gas discovered in the experiment, we modified the method of ballast gas, which usually consisted of two main components and diluted with a single ballast gas. In our experience, the main diffusing gases were diluted not with one, but each with a separate gas. These gases differed little in their diffusion properties from the main diffusing gases. For this experiment, the propane in the upper cylinder was replaced with the nitric oxide that was closest to the required condition.

Figure 2 shows the concentration of nitrogen oxide in the second system depending on the pressure. The conditions for conducting the experiment are the same as for the previous system 1.

A study carried out for the system

$$0.575He + 0.426N_2O - 0.425C_3H_8 + 0.574CH_4$$

showed that in the case of instability, the transfer of nitrogen oxide significantly exceeds the amount of propane in the diffusion of a mixture of helium and propane into a mix of methane and propane. If in the first system the concentration of propane in the lower cylinder increased by only 0.054 moles (Figure 1), then from Figure 2 it can be seen that the nitrogen oxide concentration in the second system changed by almost 0.24 moles. Thus, if you identify the propane in the upper cylinder of the first system with the nitrogen oxide in the same cylinder of the second system, the amount of propane is approximately 0.196 moles smaller than the nitric oxide, i.e. the difference is very significant.

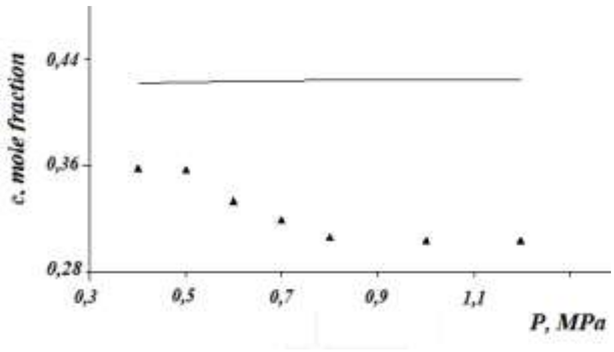

Figure 2 – Change of the concentration N_2O in the $0.575He + 0.426N_2O - 0.425C_3H_8 + 0.574CH_4$ system's upper cylinder depending on the pressure (points are the results of the experiment, a straight line is the theoretical calculation)

As shown in Figure 1 and 2, the change in the concentration of diffused propane and nitrogen oxide from the pressure is similar, starting from 0.5 MPa the propane concentration decreases, then from 0.7 MPa there is a slight, but a noticeable increase in the propane concentration and further increase in pressure leads to a decrease in the amount of diluent gas passed by $p = 1.0$ MPa. A similar change in nitrogen oxide concentration is observed in the four-component system

$$0.575He + 0.426N_2O - 0.425C_3H_8 + 0.574CH_4,$$

for which the observed feature is more noticeably expressed. The results of the diffusion study in the ballast gas systems under investigation indicate that the effect of the diluent gas on the transfer of the two main gases is significant. By choosing the appropriate ballast gas, you can either speed up, slow down, or leave the diffusion mixing process unchanged.

The resulting experimental data indicate that the circulation of ballast gas allows to maintain the unstable nature of multi-component diffusion for a long time, slowing the transition to stable mass transfer. At the initial stage, the role of convection is great, the transfer of components is significant and the experiment allows to quantify it. The replacement of propane with nitrogen oxide in the second system also indicates the occurrence of an unstable diffusion process. The transfer of nitrogen oxide at the expense of its own concentration gradient (molecular transfer) compared to the transfer by convection can be neglected. The influence of convective flows caused by unstable diffusion in both systems is significant. The "unrecognized" transfer of the diluent gas in the first system due to its circulation is significant. This can be traced in experiments in the second system. The presence of its own gradients in the "heavy" components, as evidenced by the study, is minor and the main redistribution of concentrations at the initial stage of diffusion appears to have been mainly due to the resulting convection.

Conclusion

Thus, the study of the system $He + N_2O - C_3H_8 + CH_4$ showed that in an unsustainable diffusion process, the transfer of nitrogen oxide is significantly greater than the propane transfer in the diffusion of a mixture of helium and propane into a mix of methane and propane, since in this system it is impossible to divide the propane flows in opposite directions. This suggests that in a system $He + C_3H_8 - CH_4 + C_3H_8$ during an unstable process, the diluent gas (propane) circulates through the diffusion channel from one column to another, continuously participating in the process. In the lower cylinder, propane is transported by a convex flow, the density of which is greater than the average density in the mixture, and in the upper, by a flow of density less than the mean density. The data indicate that the circulation of ballast gas enables the unstable nature of diffusion for long periods of time. The process in this case is self-organized (self-reproduced). Such self-sustainment continues as long as the main diffusing gases (helium and methane) at a sufficient concentration of propane contribute to the formation of structures leading to unstable diffusion

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