EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF FLOW OF VISCOUS LIQUID ON TRANSPORT PROCESSES

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The authors have made an experimental examination and verification of the molecular separation effect in binary mixtures under the influence of viscous momentum transfer.

Investigation of heat and mass transfer processes by the methods of the thermodynamics of irreversible processes is a matter of great interest, since they offer the possibility of intensifying existing methods of separation in binary mixtures and, also, as has been shown in [1], of developing a new method. In general the transfer of momentum of apparent motion in gas mixtures is determined by a second-order tensor and, in accordance with the Curie principle, it may be compared with transfer of heat or mass. However, in some particular cases there may be an interaction between the transfer of mass and of momentum of apparent motion. This may be demonstrated by a statistical method based on the generalizing Boltzmann distribution law.

Detailed analysis shows that in the given case, terms of the second and third approximation have an appreciable influence. It is therefore interesting to determine, by purely experimental means, the effectiveness of separation due to motion in gas mixtures in the presence of laminar flow.

Some experimental confirmation of this phenomenon is offered by one of the patents [3] and work carried out in the Institute of Heat and Mass Transfer AS BSSR in 1963 on the flow of binary gas mixtures in capillaries.

The basic shortcoming of these investigations is the low reliability of the results obtained, associated with the small value of the elementary separation effect.

It is known that the elementary separation effects can be amplified by opposing the interacting systems. This principle, in particular, is widely used in thermal diffusion equipment.

To investigate the above effect, we built the experimental apparatus shown schematically in Fig. 1a. It consists of a disk 2 rotating above a fixed base 1, with the binary mixture to be separated located in the gap between them. When the disk rotates in the closed space formed by the fixed base and the side walls, a circulation loop is generated: the binary mixture filling the working volume moves on the rotating disk from the center to the periphery, and on the fixed base—from the periphery to the center. In each of the two streams, if they do not intermingle, a transverse molecular flow of the mixture components is created, due to the angular velocity gradient in the axial direction. This elementary effect is amplified by the radial motion of the streams in opposite directions.

Thus, if in this type of apparatus, we create conditions which prevent intermixing in the axial direction, we would expect to find an appreciable separation effect. It was established experimentally in [4] that, in certain hydrodynamic regimes, there is created in the working space a layer of gas (3 in Fig. 1a) rotating with angular velocity less than that of the disk. The quantitative relations determining the conditions for the existence of such a layer are given in [5].

This layer behaves as a quasi-solid, and in it the axial velocity is zero on the greater part of the disk radius, apart from the regions adjacent to the center and the rim of the disk. This means that under certain hydrodynamic conditions, one can avoid transverse mixing of the streams and achieve opposing motion.

The experimental apparatus was built in accordance with the scheme of Fig. 1a, the general form being shown in Fig. 1b. The main parts of the apparatus are the hollow disk 2 (in the sketch it is shown in the extreme low position) and the cooler 1. The surface of the working space, formed by parts 1, 2, 3, and 4 (3 and 4 are the cylindrical and conical parts of the case) is chromed. The gap between the disk and the base is controlled in the range 0–15 mm by the nut 5. The drive is from a dc motor with the speed regulated in the range 10–500 rpm through the pulley 6. Sealing is effected via the gland 7 and the ring seals 8. The connecting tubes 9 and 10 on the bottom of the cooler serve for drawing off samples of the working substance from inside the column, and are made in the form of capillary tubes, terminating in enlarged sections with rubber stopper inserts. Tube 11 is for pumping down the internal volume, and 12—for filling it with the gas mixture or aerosol. Filling with liquid is accomplished through the central tube 9 in the bottom of the column.

During fabrication of the apparatus the bottom and the disk were made parallel. A gauge check of disk wobble showed that it did not exceed 20 μ. The possibility provided for heating the disk and cooling the fixed base may be used for investigating the thermodiffusion process in conditions of forced motion of a liquid.

The first tests were visual, and were carried out with the working volume between the disk and the fixed base filled with tobacco smoke. In these tests the bottom 1 (Fig. 1b) was replaced by another, made of thick plexiglas, and the disk surface was blackened. The tests were performed for various values of the gap

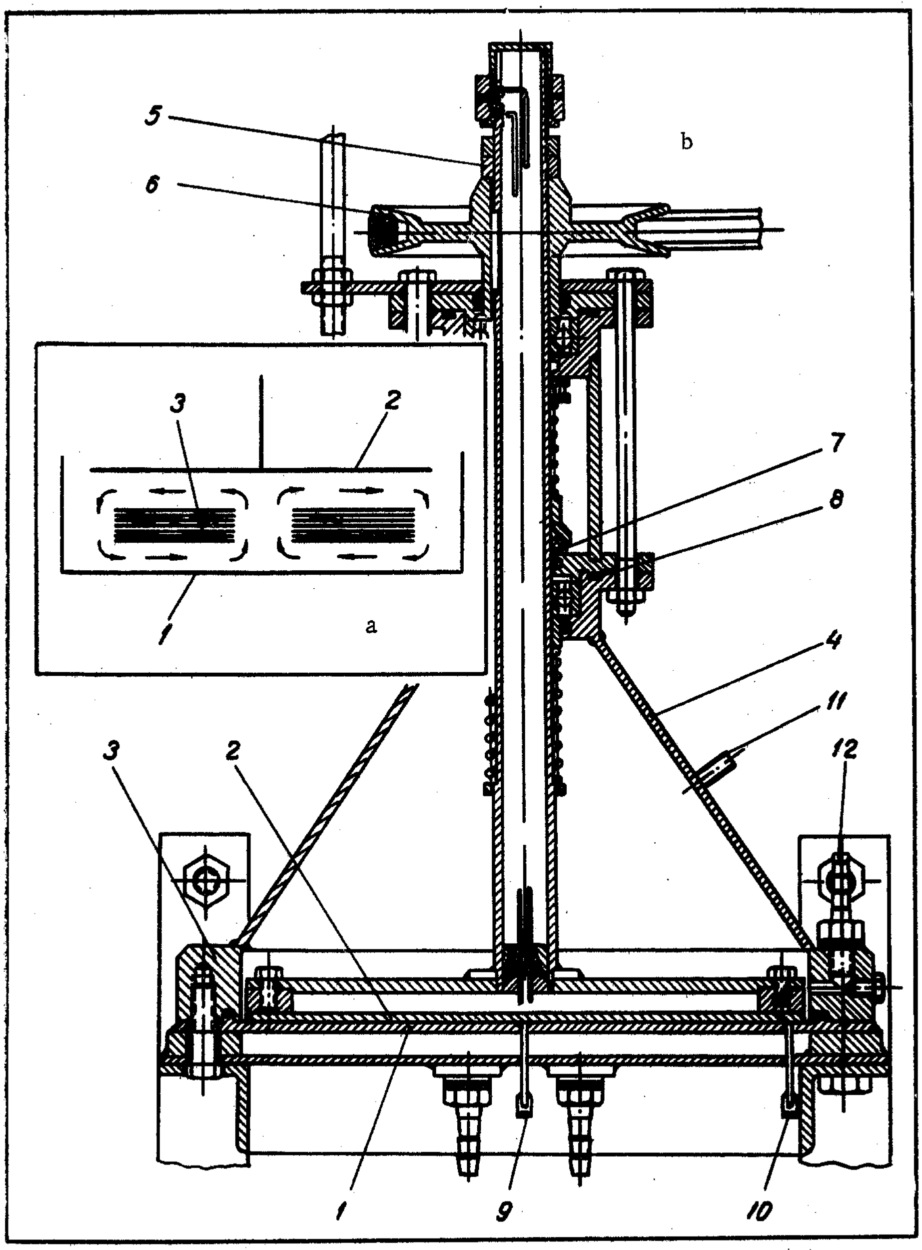

Fig. 1. Schematic of the principal (a) and general view (b) of the apparatus.

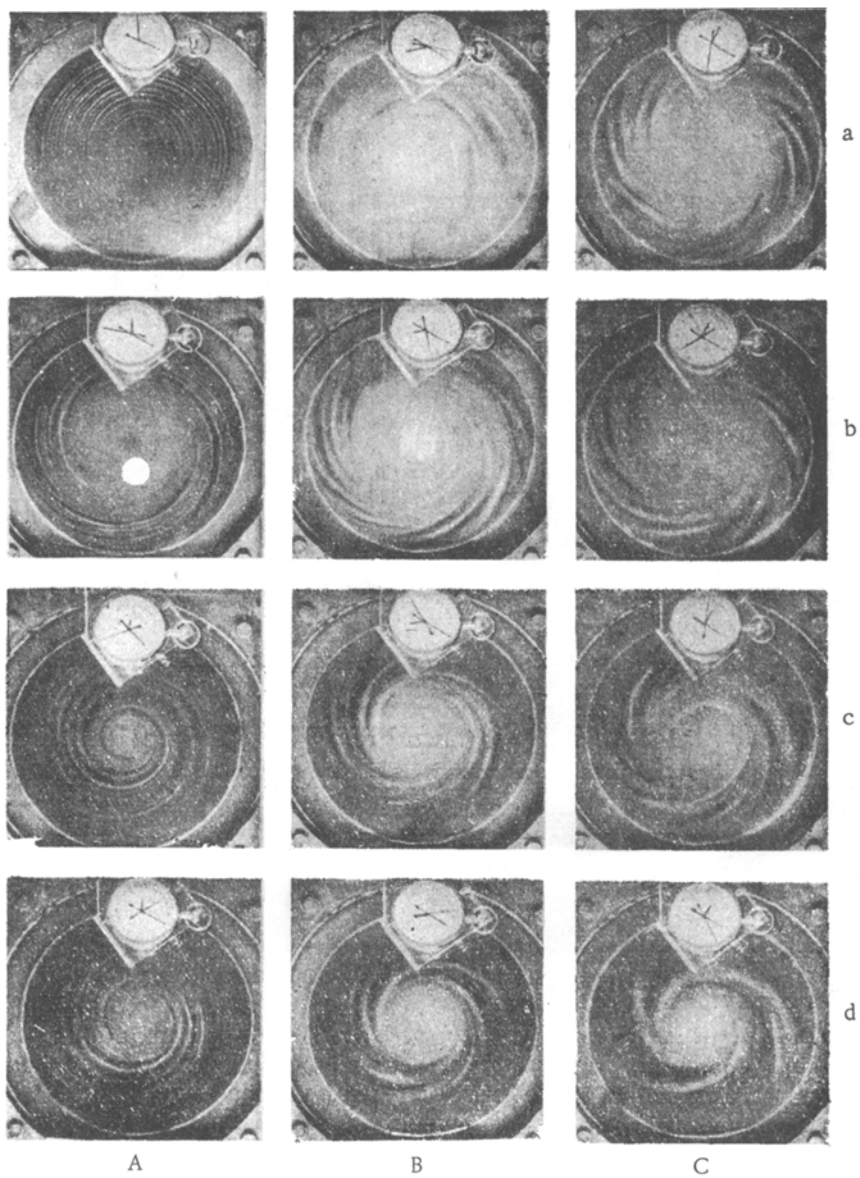

Fig. 2. Motion picture photographs of separation of an aerosol in the apparatus shown in Fig. 1, with n = 30 rpm: A—with δ = = 3 mm (a—0 sec, b—15, c—33, d—56); B—6 (a—0 sec, b—6, c—20, d—29); C—9 (a—0 sec, b—4, c—15, d—27).

between disk and base and for various rates of rotation. The dynamics of the process were recorded with a motion-picture camera.

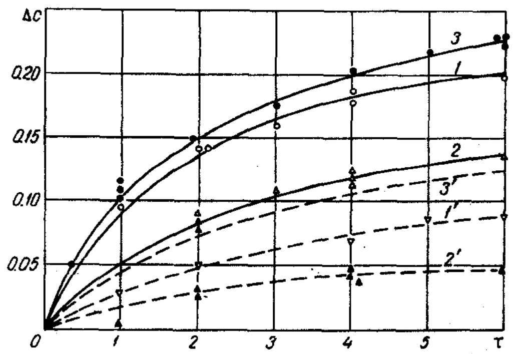

Fig. 3. Variation of sugar concentration ΔC (%) in time τ (hr): 1 and 1') for the center and the periphery of the disk with n = 30 rpm and δ = 0.15 mm; 2 and 2') the same, with 15 rpm and 0.15 mm; 3 and 3') with 15 and 0.5.

The test technique consisted of setting the required gap, presetting the electric drive system control to obtain the desired rate of rotation, stopping the motor, admitting the smoke, and switching on the camera and the motor to bring the disk into motion.

A peculiarity of the visually observed picture in all cases was that the smoke, forming characteristic spirals, rushed towards the center, sweeping the entire space between the disk and the base, and forming a thick cloud at the center.

When the equipment was dismantled, a coating of precipitated tobacco smoke particles was clearly evident at the center of the inside face of the base.

The most sharply defined picture was seen at small rotation rates, it being difficult to catch the succession of the separate stages at high rates due to the rapid completion of the process.

Figure 2 shows individual frames taken with the motion-picture camera. From a comparison of the results it may be seen that the separation process was completed more quickly when the gap was increased; then the angle formed by the spirals to the circumference of the disk increased.

Thus the tests confirmed that in equipment of the type described, it is possible to separate an aerosol from air under isothermal conditions.

It was of interest to ascertain whether or not the effect in question would also occur in molecular binary mixtures. Investigation of the molecular separation process was perfoemed with an aqueous sugar solution for values of the gap between the disk and the fixed base in the range 0.15–0.8 mm and at 15–100 rpm. The main problem was reliable concentration measurement (bearing in mind the small separation effect) with sufficient sensitivity and accuracy. These factors also determined the choice of a refractometer as the method of analysis, the samples being analyzed on the RPL-2 precision refractometer.

Figure 3 shows the results of these tests, from an examination of which it may be concluded that the general law of concentration of the heavier component of the mixture at the center of the disk, established with an aerosol in the above-mentioned tests, is also confirmed in the case of molecular solutions. The process of increase of concentration clearly proceeds over the whole radius of the disk, moving from the center to the periphery, as is seen in Fig. 3, where the curves of concentration growth at the disk periphery differ from those at its center. Increased rate of rotation increases the separation effect (Fig. 3), which is in conformity with theoretical ideas as to the transport mechanism under the action of a velocity gradient.

The influence of increase of the width of the gap between the disk and the base on the course of the process is shown in Fig. 4. It may be seen from the figure that, with increase of the gap, there is an increase in the final concentration reached at any given time. The explanation of this phenomenon is most likely that increase of the gap creates hydrodynamic conditions in the gap such that the influence of mixing in the axial direction is appreciably reduced. However, the time to attain the steady state is then increased; thus, while for δ = 0.15 mm and n = 15 rpm the steady state is reached after four hours, for δ = 0.25 mm and the same rate of rotation this condition is still not attained after eight hours, this being due to a slowing down of diffusion transport, for which we may consider, as an approximation, that the time to reach the steady state is related to the square of the gap between the disk and the base.

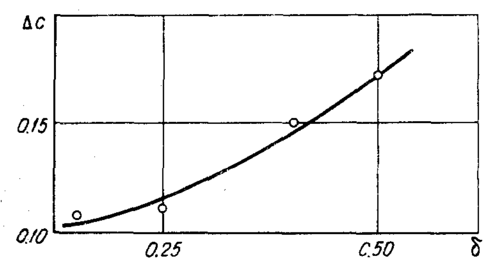

Fig. 4. Variation of sugar concentration ΔC (%) at disk center as a function of the gap between the disk and the fixed base, δ (mm), with n = 15 rpm.

It should be noted that separation of a molecular sugar solution in apparatus of the type examined is sometimes characterized by instability. Periods of increased concentration are followed by periods of reduced concentration, and then of fresh increase. We have not as yet succeeded in explaining this phenomenon.

The investigation conducted is thus an experimental confirmation of the existence of the separation effect in a laminar flow of a binary mixture predicted in [1,2].

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