DIFFUSION LENGTH IN A STEFAN CELL

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The interference method is used to determine the actual diffusion length in the evaporation of a liquid in a Stefan cell. A recommendation is made on the velocity of the gas flow at the open end of the cell in experimental determinations of interdiffusion coefficients by the Stefan method.

In measurements of interdiffusion coefficients (IDC) by the Stefan method, the diffusion length is determined on the basis of preliminary experiments. If the rate of flow of the gas has no effect on the resulting transport coefficient, then this means that a nearly zero concentration of vapor of the evaporating liquid was created at the open end of the diffusion cell (boundary condition method). It was established experimentally in [1, 2] that such flow rates fall within the range from 5 to 35 liters/h (corrected for normal conditions), depending on the parameters of the experiment and the systems studied. Here, the velocity of the gas lies within the range from $11.1 \cdot 10^{-2}$ to $77.4 \cdot 10^{-2}$ m/sec. The Reynolds number does not exceed 460. If the gas velocity is too low, diffusion resistance develops outside the diffusion cell and the actual length of the diffusion path becomes greater than h — the geometric dimension between the meniscus of the liquid in the section H—H and the open end of the cell in the section O—O (see Fig. 1). Thus, the value determined for the IDC turns out to be lower than the true value. If the flow rate of the gas is too high, turbulence develops inside the diffusion cell in its upper region and the true diffusion length becomes less than h; this means that the value found for the IDC will be too high.

We conducted our experiments on a unit of the type described in [3]. The diffusion cell was a cuvette with external dimensions of 23 × 29 × 94 mm (transparent side 29 × 89 mm) and internal dimensions of 4 × 4 × 89 mm. The length of the beam inside the cuvette was 4 mm. The cuvette was made of plane-parallel quartz plate prisms connected by the method of deep optical contact. The unit was placed between the illuminating and collimating parts of an IAB-451 Tepler instrument converted into a double-slit interferometer. The light source was an LG-75 helium-neon laser. The wavelength was 6328 Å. The radiation produced by the laser was highly monochromatic [4]. The beam was directed perpendicular to the transparent side of the cuvette.

The evaporating liquid was ethyl ether, while the gas phase was air. The latter was regarded as a one-component pseudo-gas. Both components were very pure. The parameters of the experiments: temperature 295.2 K; pressure 750 mm Hg.

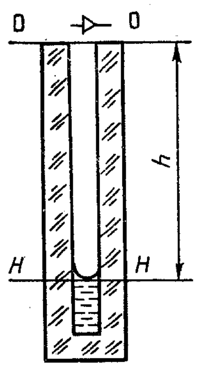

Fig. 1. Sketch of Stefan diffusion cell.

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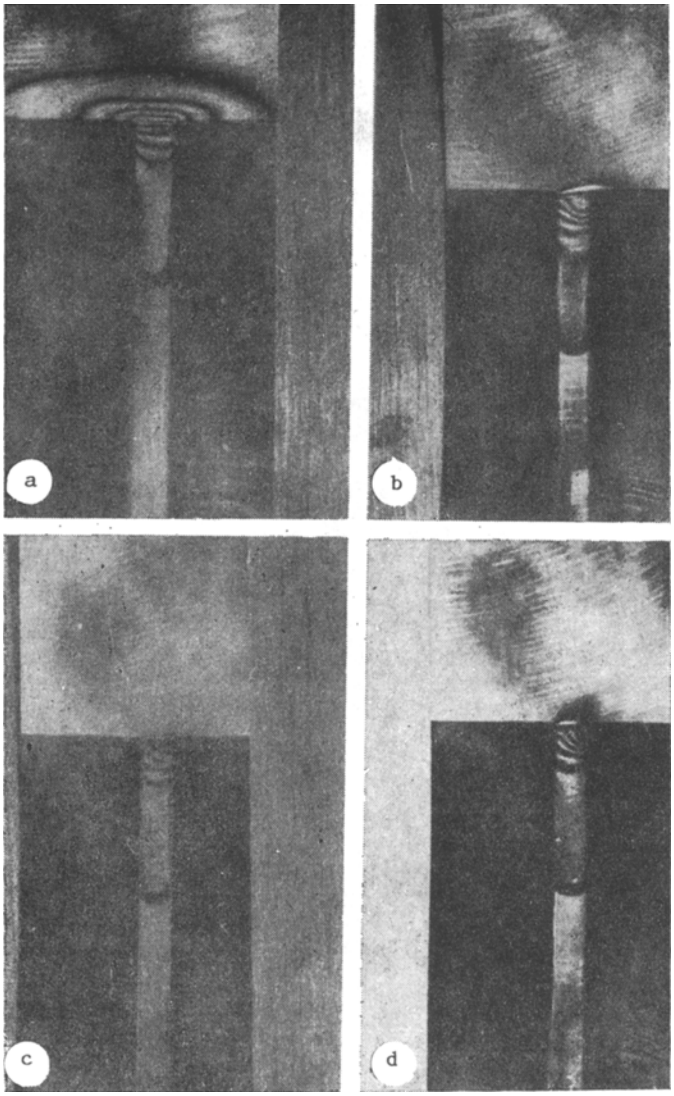

Fig. 2. Interferogram of the concentration fields of the vapor-gas mixture in the Stefan cell with different gas velocities at the top end of the cell: a) v = 0; b) $5 \cdot 10^{-2}$ m/sec; c) $44 \cdot 10^{-2}$; d) $86 \cdot 10^{-2}$.

Figure 2a shows an interferogram from an experiment in which there was no forced air flow at the open end of the cell. In this case, diffusion resistance developed outside the cell — concentration fields (interference fringes) are visible above the open end of the cell. The actual length of the diffusion path increased 35%, while the IDC is underestimated by the same amount.

Figure 2b shows an interferogram of the process with a low air velocity. Now the diffusion resistance above the cell is considerably lower. The actual diffusion length is 6% higher and the IDC is understated by the same amount. The deviation of the IDC from its true value is greater than the experimental error, since the latter was ±(1-2)% [1].

It is evident from Fig. 2c that there is no longer a concentration field above the cell and that the diffusion length is equal to the geometric dimension between the meniscus of the evaporating liquid and the open end of the cell. The value of the IDC is obtained without distortion and is equal to $9.19 \cdot 10^{-6}$ m^2/sec.

An increase in v to $77.4 \cdot 10^{-2}$ m/sec does not lead to a significant change in the concentration fields of the vapor-gas mixture inside the cell and, thus, also does not result in a change in the accuracy of the values of the IDC. On the other hand, it was established experimentally that a reduction in v to $18 \cdot 10^{-2}$ m/sec also does not appreciably affect the distribution of the concentration fields of the vapor-gas phase inside the cell or the measured values of the IDC.

Figure 2d shows an interferogram of the process obtained with a relatively high gas velocity. Under these conditions, turbulence causes distortion of the concentration fields of the vapor-gas phase in the upper part of the cell. The IDC turns out to be exaggerated by 15.8%.

When liquids less volatile than ethyl ether are used to determine the IDC in experiments conducted by the Stefan method, the lower limit $v = 18 \cdot 10^{-2}$ m/sec. This is quite sufficient to maintain a zero concentration of vapor of the evaporating liquid at the open top end of the diffusion cell.

Other conditions being equal, the rate of evaporation of liquids decreases substantially with an increase in pressure. Thus, under the conditions of compression, the lower limit of flow velocity ensures satisfaction of the boundary condition of the Stefan method.

As a result, $v = 18 \cdot 10^{-2}$ m/sec guarantees the determination of reliable and accurate values for the IDC of a broad range of binary vapor-gas systems within broad ranges of temperature (283.4-363.2 K) and pressure (0.1-98.1 MPa). This is confirmed by our findings here and by the data obtained in numerous other experiments [1, 2, 5-7].

Thus, the interferometric method has been used to establish the essential features of vapor-gas diffusion in a Stefan cell. We found that the optimum gas velocity is $18 \cdot 10^{-2}$ m/sec when the Stefan method is realized at the open end of the diffusion cell. This value ensures reliable and accurate measurement of the interdiffusion coefficients of binary vapor-gas systems composed of a wide range of substances within broad ranges of the state parameters. The results obtained in the present study are also needed to design instruments and equipment for use in environmental studies.

NOTATION

h, diffusion length or the distance between the meniscus of the evaporating liquid and the open end of the Stefan cell, mm; v, velocity of the forced flow of air at the open end of the diffusion cell in the section 0–0 (see Fig. 1), m/sec.

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