Mass Transfer Entrance Lengths in Dilute Polymer Solutions

A. P. Duduković
Faculty of Technology
University of Novi Sad
Novi Sad, Yugoslavia

In fluid streams with a high Schmidt number the diffusion sublayer is extremely thin and reaches the asymptotic thickness over a small length, so that most of the processes are carried in the fully developed mass transfer region. However, in polymer solutions Ng et al. (1980) have estimated that entrance lengths for heat transfer are greater than 430 tube diameters. The aim of this study is to investigate the effect of dilute polymer solutions, frequently used as drag-reducing agents, on mass transfer entrance lengths.

The experiments were carried out by the adsorption method based on the determination of the amount of the adsorbed matter under the conditions when the process is mass transfer controlled, as described elsewhere (Končar-Djurdjević and Duduković, 1977; Duduković and Končar-Djurdjević, 1979, 1980). Silica gel deposited as a thin film on aluminum foils (Merck, DC-Alufolien Kieselgel, Art. 5554) was used as the adsorbent, while methylene blue (Merck, Methylenblau B, Art. 1283) was used as the adsorbing species. It was shown previously (Duduković, 1985) that the mass transfer results or Sherwood number values obtained by the adsorption method in Newtonian fluids agreed well with results obtained by other methods, and with available correlations. The presence of dissolved polymer does not affect the results obtained by this method (Duduković and Končar-Djurdjević, 1984). The mass transfer results in dilute polymer solutions below the onset Reynolds number, i.e., before apparent drag reduction, are identical to those in pure fluids.

The amount of adsorbed matter was determined by measuring the reflected light intensity with a Chromaflex K-495000 Densitometer (Kontes, New Jersey). Two moving beams of light illuminate the surface of interest and the reference surface. The reflected light is carried back to cadmium sulfide cells by means of fiber optic bundles, where the reflected light intensities are compared, converted to an electrical output, and registered by the recorder. The paper speed in the recorder can be adjusted to follow the speed of the light beams.

The experiments were carried out in a 28 mm ID tube. Foils with silica gel were placed at a distance of 50 diameters from the entrance in order to assure that the hydrodynamic boundary layer was completely developed. The concentration of methylene blue was $2.5 \cdot 10^{-3}$ g/L, and the duration of each experiment was 5 min. One set of experiments was carried out using pure water and methylene blue. In the other set of experiments an aqueous solution of polyethylene oxide (Polyox WSR-301, Union Carbide Corp.; molecular weight of about 4×10^6) at a concentration of 150 ppm was used. The Schmidt number value was 1.87×10^3.

The experimental results for pure water are presented in Figure 1 and those for the dilute polymer solution are given in Figure 2. In both figures the ratio of relative light absorption for a particular point on the silica gel surface and for the point far enough from the foil edge (18 cm) is given as the ordinate. This ratio closely represents the ratio of the local and fully developed Sherwood number. The ratio of the distance measured from the leading edge of the silica gel foil and of the tube diameter is given as the abscissa. It was found that in the presence of a dilute polymer solution the mass transfer reduction for fully developed Sherwood numbers was between 10 and 55% (Duduković, 1985).

Comparison of the results in Figures 1 and 2 shows that the dissolved polymer had no effect on the mass transfer entrance length for the range of Reynolds numbers investigated and for polymer concentrations up to 150 ppm. In both cases the mass transfer entrance length was about 1.5 tube diameters. These results are in agreement with those of McConaghy and Hanratty (1977).

It is important to point out that the mass transfer entrance lengths are quite short, since Cho and Hartnett (1980) concluded that entry lengths could be over 34.5 tube diameters, based on the experimental data of Virk and Suraiya (1977). Actually, Virk and Suraiya determined the average mass transfer coefficient by the soluble pipe wall method using two tubes coated inside with trans-cinnamic acid. The tube lengths were 34.5 and 69 times the inner tube diameter. From these results,

The author is presently at Oregon State University, Department of Chemical Engineering, Corvallis, OR 97331.

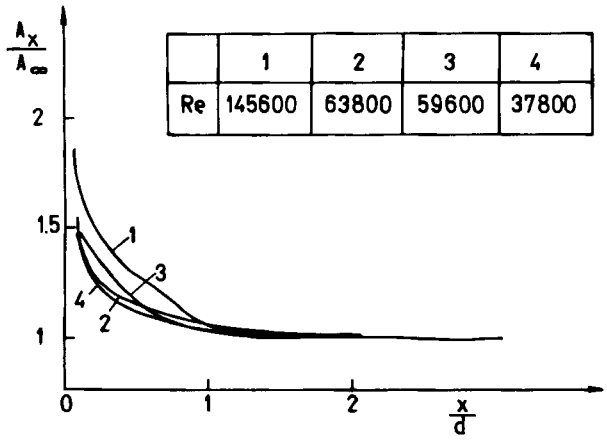

Figure 1. Mass transfer entrance lengths for water.

which were the same, one could only conclude that the mass transfer entrance length could not be longer than 34.5 times the inner tube diameter. They did not measure the local mass transfer coefficients as done in this study.

Our results also differ from those of Yoo and Hartnett (1975) and Ng et al. (1980) for heat transfer entrance lengths in polymer solutions. They reported entrance lengths in excess of several hundred tube diameters. However, this difference could be the result of the different effect of polymer additives on eddy mass diffusivity and eddy heat diffusivity. It could also be caused by an order of magnitude higher polymer concentrations in their experiments.

In conclusion, we present here firsthand experimental evidence on the variation of local mass transfer coefficients which clearly indicates that in fully developed flows at high Schmidt numbers the mass transfer entrance lengths are only of the order of one to two tube diameters for both Newtonian fluids, with or without drag-reducing agents. We cannot conclusively comment on the apparent difference between heat and mass transfer entry lengths.

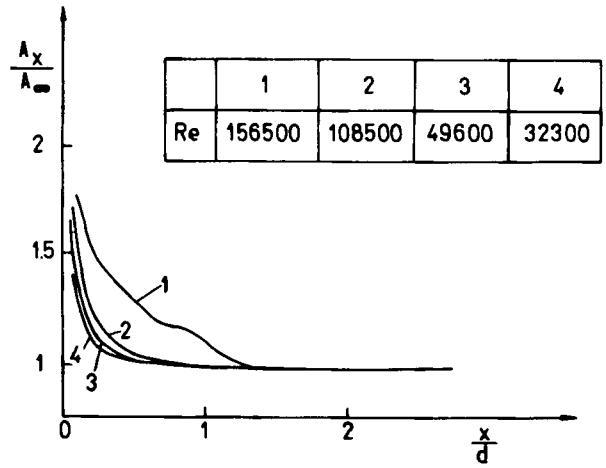

Figure 2. Mass transfer entrance lengths for polyethylene oxide solution.

% Drag Reduction (DR) Obtained

Curve	1	2	3	4
DR	39%	33%	20%	6%

Notation

A_x = relative light absorption at the point a distance x from a foil leading edge
$A\infty$ = relative light absorption far enough from a foil leading edge
d = tube diameter
Re = Reynolds number
x = axial distance

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