The electrodiffusional theory for wall shear stress measurement by a two-strip probe: a journey to near-wall region hydrodynamics

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Transport phenomena occurring in the near-wall region depend on the hydrodynamics in the boundary layers and are, therefore, significantly influenced by wall shear stress behavior.[1] For this reason, knowledge of the velocity gradient in the immediate vicinity of the wall can be used to optimize problems concerning fluid dynamics, such as, for example, the design of vehicles to reduce drag, the intensification of chemical processes in the industry, or towards findings of optimal conditions during the cultivation of biological material in biotechnology applications.

One of the possible techniques for non-invasive measurement of wall shear stress is the electrodiffusion method developed by Reiss and Hanratty.[2,3] The basic principle of the electrodiffusion method is to measure the limiting electric current flowing through the electrode flush-mounted with the wall. On the basis of the value of the electric current it is subsequently possible to describe hydrodynamics near the wall. Nevertheless, in order to obtain the studied hydrodynamic quantities from the electric current signal, appropriate relationships are needed, which can be found either by performing a calibration or by using a theory that analytically describes the investigated problem. The theoretical approach is based on the calculation of the mass transfer coefficient from measured electric current. However, to simultaneously determine the magnitude and direction of the wall shear stress, two independent electrical signals are desired, and thus the need arises for the use of a two-segment measuring probe.

This contribution deals with a new theory[4] describing mass transport in the vicinity of the measuring two-segment strip probe. Analytical formulas for the mass transfer coefficients of the front and the rear electrodes were derived. At the same time, the correctness of these formulas was confirmed by the numerical solution of the convection-diffusion transport equation. Furthermore, a methodology for possible experimental data treatment was proposed. From the analysis of the electric current ratio predictions for different measuring probe geometries, an optimal probe configuration was found with respect to the sensitivity of the flow direction measurement. Applying the presented derived theory to the experimental measurements makes it possible to determine both a wall shear stress magnitude and its direction.

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References

1. Havlica, J.; Kramolis, D.; Huchet, F. *Int. J. Heat Mass Transf.* **2021**,165, 120610.
2. Reiss, L. P.; Hanratty, T. J. *AIChE J.* **1962**, 8, 245-247.
3. Reiss, L. P.; Hanratty, T. J. *AIChE J.* **1963**, 9, 154-160.
4. Harrandt, V; Kramolis, D.; Huchet, F.; Tihon J.; Havlica, J. *Int. J. Heat Mass Transf.* **2023**, article accepted for publication.