EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF LORENZ FORCES ON LOCAL MASS TRANSFER AND NEAR WALL TURBULENCE BY MEANS OF ELECTRODIFFUFION PROBES

X. Adolphe[1], *S. Martemianov*[1], *A. Piteau*[1], *T. Weier*[2], *G. Gerbeth*[2]

[1] *Laboratory of Heat Studies, LET – UMR CNRS no 6608 , ESIP – University of Poitiers, 40 avenue du Recteur Pineau, 86022 Poitiers Cedex, France*
[2] *Forschungszentrum Rossendorf, P.O. Box 51 01 19, 01314 Dresden, Germany*

Introduction. There are great opportunities for using of magnetic actions for control of near wall turbulence and local mass transfer [1]. Very promising trend in boundary layer control in natural conditions (sea water) is related with utilization of Lorenz forces with possible applications in the field of naval construction [2, 3]. Another interesting way deals with electrodeposition of coatings, including hard, bright coatings and electrical interconnects. The experimental study of MHD effects is very difficult task. We are confronted with the necessity of studying turbulence characteristics in the very vicinity to the wall (viscous sublayer) were the traditional experimental approaches to flow measurements (thermoanemometry, LDA and PIV) cannot be used. Utilisation of numerical methods are rather difficult in this case also. Indeed, using of LES is strictly dependent on the development of closure models for viscous sublayer and utilization of DNS is limited to low Reynolds numbers.

Electrochemical measurements open a very interesting way to studying of flow and mass transfer characteristics in the near wall region. Unfortunately a number of technical problems should be solved in order to use successfully this method. The main difficulty is related with calibration of electrodiffusion probes in flows under magnetic field influence. The aim of the present paper is to present some first results concerning electrochemical flow diagnostics of flows under magnetic field influence.

1. Experimental device. Experiments were conducted in Poitiers in a two-dimensional rectangular channel with a cross section of 120 mm × 12 mm. The measurement section was located 2 m downstream the entrance to ensure well developed turbulent flow conditions in the range of the Reynolds numbers investigated ($\mathrm{Re} \in [10000 - 40000]$). This measuring section (fabricated in Dresden) was equipped by flush mounted permanent magnets and INOX electrodes allowing to generate a wall parallel Lorentz forces in the streamwise (x) direction, see Fig. 1. The Lorentz force $\mathbf{F}$ results from the vector product of the current density $\mathbf{j}$ and the magnetic induction $\mathbf{B}$

$$F = j \wedge B \tag{1}$$

and the current density itself is given by Ohm's law

$$j = \sigma(E + U \wedge B) \tag{2}$$

where E denotes the electrical field, U is the velocity and σ is the electrical conductivity.

In our experiments the electrolyte was $25\,\mathrm{mol}\cdot\mathrm{m}^{-3}$ aqueous solution of $\mathrm{K_3Fe(CN)_6}$ and $\mathrm{K_4Fe(CN)_6}$, with an addition of $300\,\mathrm{mol}\cdot\mathrm{m}^{-3}$ $\mathrm{K_2SO_4}$ as the

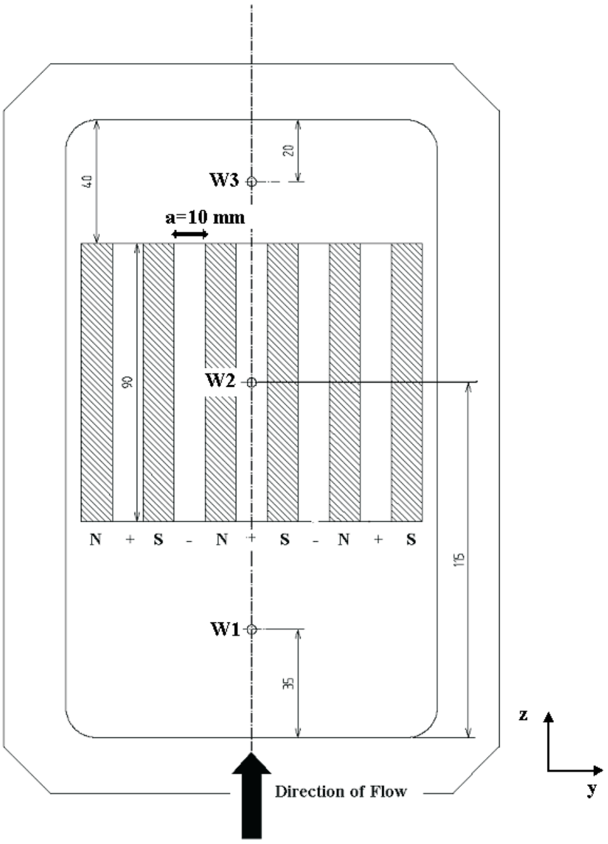

Fig. 1. Configuration of measuring section equipped by electrodes and permanent magnets.

supporting electrolyte. The electrical conductivity of the solution at $T = 26°\mathrm{C}$ was about $\sigma = 3.8$ S/m. For low conductivities in order of 10 S/m the currents generated by the $\mathbf{U} \times \mathbf{B}$ term are very small, even for magnetic fields of several Tesla. In this condition the current density in the electrolyte can be obtained as the first approximation by resolution of the Laplace equation (primary current distribution). After the Lorenz force can be calculated. The example of calculations [2] of the Lorentz force F in y-z plane is illustrated by Eq. (3)

$$F = \frac{\pi}{4} jB\mathrm{e}^{-\frac{\pi}{a}y} \quad . \tag{3}$$

Magnetization of the magnets which were used in our experiments corresponds to $B = 0.2$ T, the weight of the electrode $a = 10$ mm. The applied current density $j = I/S$ can be estimated by means of applied current I and electrode surface area S. In this way it is possible to estimate the Hartmann number Z:

$$\mathrm{Z} = \frac{1}{4\pi} \frac{jBa^2}{\rho U \nu}. \tag{4}$$

On Fig. 2 we present the estimation of Hartmann number Z as the function of $\tau^{1/3}$, where the wall shear stress on the wall τ is obtained via the pressure drop Δp measurements. We stress that our channel is well calibrated from the hydrodynamical point of view, in particular in turbulent regime we have confirmed using the flow rate and the pressure drop measurements the classical relation for the friction factor: $\lambda = 0.32/\mathrm{Re}^{-1/4}$.

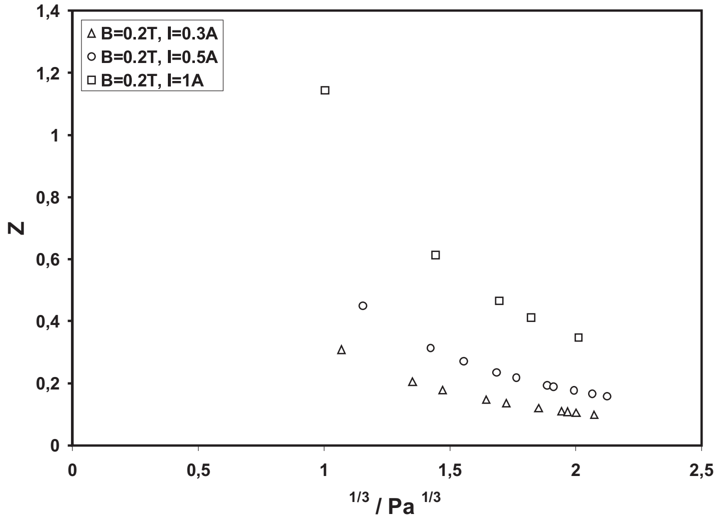

Fig. 2. Dependence of the Hartmann number from the wall shear stress (measuring via the pressure drop) in our experiments.

For electrochemical flow measurements the working Pt electrode of $d = 0.5$ mm diameter was embedded within a counter INOX electrode of $\phi = 3$ mm diameter. The probe was fixed flush mounted within a large INOX electrode (anode) using for the creation of the Lorentz forces. The working electrode was polarized with respect to counter electrode and the current in this circuit was used as informative parameter.

2. Examples of obtained results. Voltage/current measurements indicate the existence of the diffusion plateau. It is well known, that in this case the limiting diffusion current I_{lim} is directly related with the mass flux J of the electroactive species to the electrode via the Faraday law. Moreover, the limiting diffusion current can be related with the local wall shear stress at the electrode surface τ via the Leveque equation.

On the Fig. 3 are presented the results of the magnetic field influence on the limiting diffusion current using the wall shear stress (right) or Reynolds number

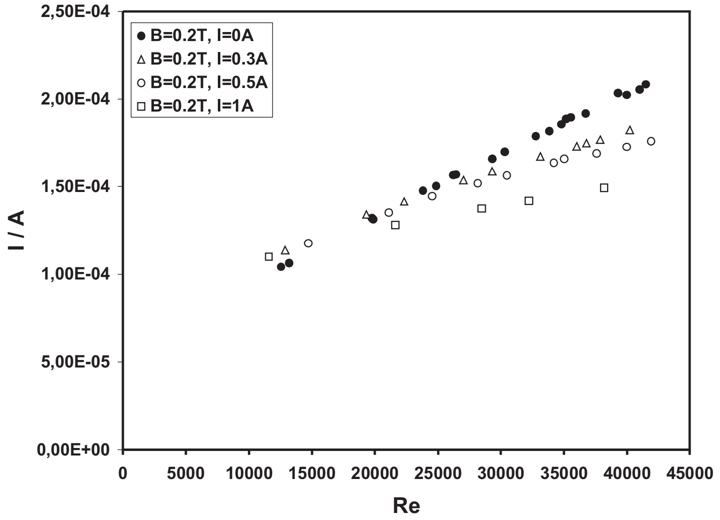

Fig. 3. Influence of the Lorentz force on the limiting diffusion current.

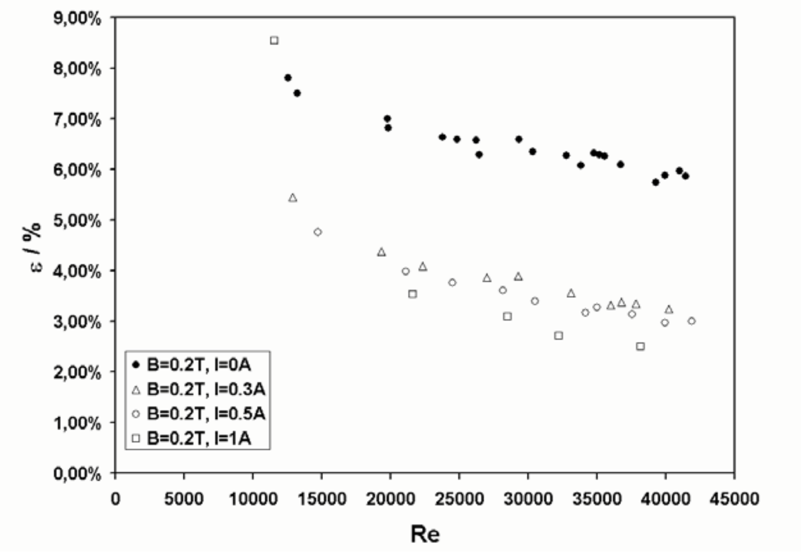

Fig. 4. Influence of the Lorentz force on the intensity of turbulent pulsations.

(left) coordinates. We can see that in these experimental conditions a wall parallel Lorentz forces decreases a local mass transfer to a wall.

Statistical analysis of current fluctuations can be interpreted [4, 5] in terms of turbulent mixing of a passive scalar (concentration) in the near wall region. So we can use electrochemical flow measurements for the study of the influence of Lorenz forces on this turbulent mixing within the viscous sublayer. The Fig. 4 illustrates the influence of the Lorentz forces on the intensity of the near wall turbulent pulsations. On this figure the factor ε corresponds to the ratio between r.m.s. of current fluctuations and the mean current. We see that the magnetic action diminishes considerably the turbulent pulsations.

3. Conclusion. This study shows that electrochemical flow diagnostics can be applied for the study of the magnetic field influence on the near wall mass transfer and near wall hydrodynamics. Using this experimental method we have confirmed that parallel Lorentz forces can decrease the local wall shear stress. Also, we have confirmed the important diminishing of the intensity of the near wall turbulent pulsations under magnetic field influence. From the other hand, the fine structure of the near wall turbulence (skewness and flatness factor) is not considerably influenced by the applied Lorentz force.

REFERENCES

1. T.Z. Fahidy. Magnetoelectrolysis. *J.Applied Electrochemistry*, vol. 13 (1983), p. 553.
2. T. Weier, U. Fey, G. Gerberth, G. Mutschke. Boundary layer control by means of wall parallel lorentz forces. *Magnetohydrodynamics*, vol. 37 (2001), p. 177.
3. A.K. Gailitis, O.A. Lielausis. On the possibility of drag reduction of a flat plate in an electrolyte. *Applied Magnetohydrodynamics*, vol. 12 (1961), p. 143.
4. B.M. Grafov, S.A. Martemianov, L.N. Nekrasov. *Turbulent diffusion layer in electrochemical systems* (M, Nauka publ, 1990), 293 p.
5. S. Martemianov, L. Danaila. On the study of electrochemical turbulent noise in a stirred vessel. *Fluctuations and Noise Letters*, vol. 3 (2003), no. 4, pp. L463–L471.