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Comments on Turbulence Measurement in Water using an Electrokinetic Probe

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Recently, Chuang and Cermak presented a paper (*1*) on turbulence measurements in a pipe flow of distilled water using an electrokinetic probe. They are to be commended for their pioneering study of the probe technique. However, the shortcomings of their analyses also must be pointed out.

In the section on theory, they presented the following equation for charge transport in an incompressible fluid:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \underset{\rightarrow}{U}) + \frac{\rho}{\tau} = 0 \tag{1}$$

To obtain Equation (1), one must assume that the conductivity of the fluid is a constant, and that the charge transport due to diffusion is negligible. Without these assumptions, the corresponding equation, as derived by Gavis and Koszman (*2* to *5*), becomes

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \underset{\rightarrow}{U}) + \frac{\rho}{\tau} = \frac{\lambda^2}{\tau} \nabla^2 \rho + \nabla\psi \cdot \nabla\sigma \tag{2}$$

where the two terms on the right-hand side of Equation (2) represent the effects of diffusion and variation in conductivity.

As shown by Gavis and Koszman, the assumption of a constant conductivity is valid only for fluids of low dielectric constant and low conductivity, such as electrokinetic effects in hydrocarbons or charge transport phenomena in gases. For water and solutions thereof, the conductivity varies essentially over the diffuse layer and the term $\nabla\psi \cdot \nabla\sigma$ can not be omitted from Equation (2). It seems doubtful that any result derived from Equation (1) can be considered even as a good approximation for water and its solutions. The omission of the diffusion term is also subject to question, especially in regard to the diffusion perpendicular to wall.

Another assumption used by the authors, following the derivation of Equation (5) of their paper, was that $\sigma\nabla\phi = \bar{\rho}\, \underset{\rightarrow}{u}$. Mathematically and physically, this means the fluctuating current densities due to turbulence convection at any point in the fluid were considered to be counterbalanced in each direction by the corresponding fluctuating conduction-current densities at the same point. If this assumption were true, it would then be impossible to record any electrokinetic-potential fluctuation between any two electrodes located on a pipe wall, since the convective current density at the wall must then be zero in order to satisfy the no-slip condition. However, experimental findings indicated the contrary to be true. Bocquet (*6*), Binder (*7*), Duckstein (*8*), and Liu (*9, 10*) all measured electrokinetic-potential fluctuations by wall electrodes.

In the section called *Discussion of Experimental Results,* Chuang and Cermak made one more assumption regarding the electrokinetic-potential fluctuations. They assumed that the potential fluctuation of electrokinetic-potential difference between two closely spaced electrodes aligned in any direction is considered to be linearly proportional to the fluctuating turbulent velocity (of the neighboring fluid?) in that direction.

It should be pointed out that to date (1968) no data taken by any other investigator except those reported by Chuang (*1, 11*) have yet confirmed this hypothesis. I have conducted a series of tests but all of them indicated no directional sensitivity (*9*). In view of this, I had to use a quite different rationale to explain my experimental data (*9, 10*). It is hoped that other researchers in this field will conduct more experiments to testify the hypotheses of directional sensitivity and linear proportionality.

NOTATION

t = time
u = fluctuating component of velocity vector
$\underset{\rightarrow}{U}$ = instantaneous velocity vector

Greek Letters

λ = diffuse-layer thickness
$\underline{\rho}$ = instantaneous true charge density
ρ = time-mean charge density
σ = conductivity
τ = relaxation time of the fluid
ϕ = fluctuating electric potential
ψ = instantaneous electric potential

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