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Instantaneous Mass Transfer Measurement and Its Relation to Turbulence Structures in Pipe Flow

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In turbulent pipe flow, since large-scale events maintain a footprint in the near-wall region (Hutchins and Marusic, 2007), we believe it will affect the mass transfer rate. In this study, we focus on effects from large-scale structures on the mass transfer rate.

In the test section, we housed eight working electrodes along spanwise direction in the pipe. The degree between each electrode is 8°. The counter and reference electrodes are located far away from the working electrodes in the downstream region, respectively. The velocity field is measured by a stereo-PIV system, shown in figure 1, which consisted of two digital high-speed cameras, a laser system, a high-speed controller, and a desktop personal computer. In this experiment, the sampling frequency of both electrode method and PIV is 1K Hz and Reynolds number, based on bulk velocity and pipe diameter is 25000.

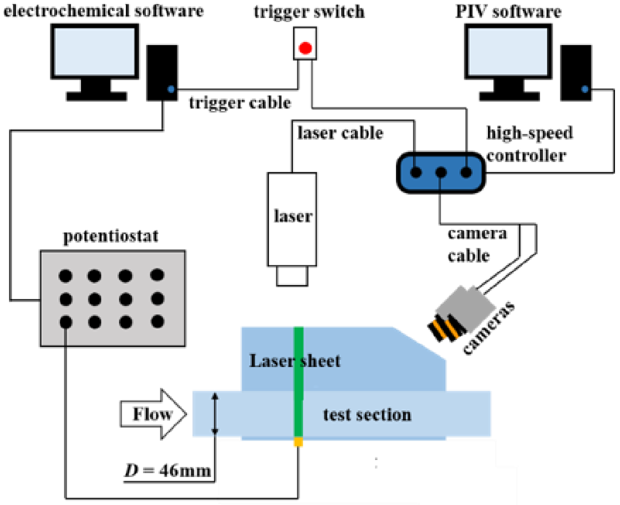

Figure 1 Schematic view of PIV system.

In order to quantitatively characterize the velocity fluctuation and mass transfer fluctuation, the coarse-grained structures are studied instead of the original flow field. We removed some parts of data, only preserve the parts, whose fluctuation is larger than one time of their standard deviation, as well as one time smaller than negative standard deviation.

$$u_I = \begin{cases} 1: & u' \geq \sigma \\ 0: & -\sigma < u' < \sigma \\ -1: & u' \leq -\sigma \end{cases} \quad k_I = \begin{cases} 1: & k' \geq \sigma \\ 0: & -\sigma < k' < \sigma \\ -1: & k' \leq -\sigma \end{cases} \qquad (1)$$

We set the time-lag as Δt, and define the correlation coefficient as

$$C_{ku} = \frac{1}{T}\int_0^T u_I(t)k_I(t+\Delta t)dt \qquad (2)$$

where u' is the streamwise velocity fluctuation, k' is the mass transfer fluctuation, σ is the standard deviation for each quantity, T is the sampling total time. The contour of two-dimensional correlation coefficient is plotted as shown in figure 2, horizontal axis Δx^+ is the flow direction, vertical axis y^+ is the distance against to the wall. In figure 2, high correlation region locates inside log-region and near wall region. And this high-correlation region is inclined toward the downstream.

$$\Delta x = u_c(y) \times \Delta t, \Delta x^+ = \Delta x u_\tau/\nu, y^+ = y u_\tau/\nu \qquad (3)$$

where, $u_c(y)$ is local mean velocity, Δt is time lag.

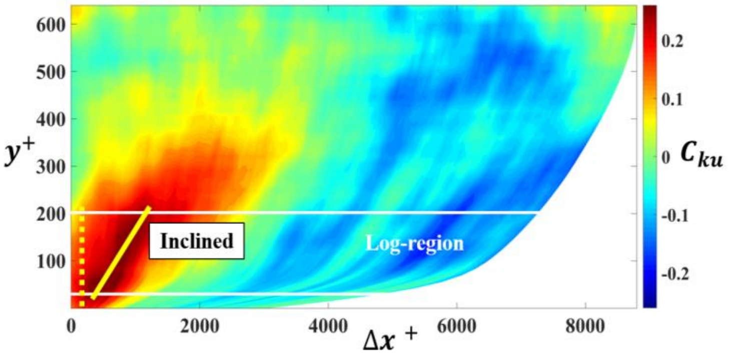

Figure 2 Two-dimensional contour of the correlation coefficient.

Therefore, the model of large-scale structures how they affect the mass transfer rate at wall is considered. The large-scale structures are carried by local mean velocity, outer region moves faster than inner region. Besides, large-scale structure has footprint on the wall, however, its effect is not perpendicular to the wall but inclined toward the downstream. Thus, these will make a time-lag between velocity and mass transfer rate.

From the simultaneous measurement of velocity and mass transfer fluctuation in the pipe flow, we characterized the large-scale structures by way of coarse-grained analysis. Large-scale structures have a significant effect on the mass transfer rate at the wall. The correlation coefficient is at almost 30% in the log-region. There is a time-lag when the velocity fluctuation affect the wall. The space correlation of C_{ku} contour shows the inclined structures toward the downstream. Therefore, the footprint might occur with time-lag.

REFERENCES

Hutchins, N., Marusic, I. 2007 Evidence of Very Long Meandering Features in the Logarithmic Region of Turbulent Boundary Layers. Journal of Fluid Mechanics, Vol. 579, pp. 1-28.