TURBULENT TRANSFER OF PASSIVE ADMIXTURE IN A JET MIXER

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Currently, the problems on heat, mass, momentum transfer enhancement in different-medium flows have been the focus for constant attention of researchers. This has been motivated by the need for solving some of practical problems on technologies used in chemical and food industries, water cleaning facilities, combustors, chemical reactors, heat exchangers, etc. Often providing fast and complete mixing of different media is one of the governing factors in such processes. Jet axis-symmetrical mixers being simple in design permit realizing both laminar and turbulent mixing of media and also combining these processes by selecting a flowrate ratio $Q = Q_D/Q_d$ of initial media. The present work considers the mixing of a turbulent jet and a co-flow where a transient hydrodynamic flow regime is achieved. A jet velocity exceeds a co-flow one. As this takes place, possible mixing regimes can be organized into two different modes: 1) a recirculation flow zone ($D/d > 1 + Q_D/Q_d$) is formed just behind a nozzle and 2) a recirculation flow zone ($D/d < 1 + Q_D/Q_d$) is not formed [1]. Here D/d is the diameter ratio. Studies of the scalar field development for the above mixing regimes are scanty. Diagnostics of the scalar field in the mixing regime with the recirculation zone is made with a frequency (1 Hz) of selecting instantaneous scalar distributions and described [2]. This has enabled one to operate with a comparatively small information volume, which is quite sufficient for calculation of two first statistical moments of turbulent characteristics, but for the analysis of high moments and probability density functions (PDFs) it should be at the minimum doubled. Of more essential is the fact that simultaneous measurements of velocity and scalar fields are absent for both regimes, thus restricting a possibility to analyze the interaction of such fields. Experimental studies are also necessary to make databases for the testing of modern theoretical mixing models that permit calculating different statistical moments responsible for fine-grained mixing – micromixing. Information on distributions of a scalar and its fluctuations opens up fresh possibilities to check the validity of the used mathematical models for scalar PDFs by comparing those calculated from measurements with the predicted ones. An example of the analytical representation of the scalar PDF is the two-parameter β-distribution widespread in different models for turbulent mixing and turbulent combustion of non-premixed flows. This work compares such a β-distribution with the identical PDF reconstructed from the experimental distributions of the scalar and its fluctuations.

In both mixing regimes a turbulent jet was considered at Re_d=10 000. A velocity field was measured by a one-component LDA over mixer cross-sections at different distances from a nozzle $0.1 < x/D < 9.1$. Diagnostics of the scalar field (in our case, passive admixture concentration) used the LIF method based on registering the radiation intensity of laser beam-induced fluorescing substance over the just same cross-sections where dynamic characteristics were measured. From the obtained scalar distributions, an autocorrelation function and an integral length scale were calculated and also PDFs, skewness and kurtosis distributions were plotted. Flow was visualized in the mixer.

The performed studies of two mixing regimes in the jet axis-symmetrical mixer revealed an essential difference in the velocity field dynamics. Over the investigated distance range $0.1 \le x/D \le 9.1$ the uniform distribution of an averaged velocity had no time to form, although when the recirculation zone was formed, the uniform distribution of the velocity was fixed within a larger area of the mixer cross-section. Turbulent fluctuation profiles in both regimes were quite uniform, starting with $x/D \ge 7.1$, and their values for the relevant cross-sections were higher in the regime without the recirculation zone.

In the mixing regime with the recirculation zone macromixing commences to the cross-section at $x/D = 5.1$. In the regime without the recirculation zone this process only approaches the commencing stage over the cross-section at $x/D = 9.1$ (Fig. 1). In the first case, the scalar fluctuation level in a quasi-uniform mixture is almost as lower as three times than in the second. Thus, the scalar field develops ahead the velocity one. As scalar transfer is determined by the flow dynamics (in this work

Sc> 1000), a faster development of the scalar field is attributed to scalar transfer affected by unsteady eddies that are generated in the mixing layer and provide this transfer at a larger distance than at that statistically determined by a jet boundary. Averaging the dynamic characteristics hides the influence of such eddies. However, the scalar field generated by them points to their determining role in the mixing process. Hence, consideration of the scalar field development as the steady process even in the regime without the recirculation zone does not reflect the real physical phenomenon. That is why, the use of the statistical turbulence models based on averaged velocity field characteristics for calculation of the scalar field yields ill-judged conclusions.

Under mixing involving the formation of a backflow zone, neglecting the unsteady behavior of the recirculation zone completely misrepresents its physical nature. Visualization of the recirculation zone and analysis of changes in the autocorrelation function are convincingly evident of the unsteady character of this flow. The oscillating motion near the mixer walls with anti-phase for regions symmetrical to the mixer axis manifests itself in changing a sign of the autocorrelation function plotted through the scalar distribution (Fig. 2). This function also shows that the recirculation zone structures interact with the jet core, which is a result of their small size. The structure of this zone is a superposition of different-size unsteady eddies but not a single steady eddy up to 3 diameters in size. Changes in the PDF and also in the skewness and kurtosis distributions for the considered regimes indicate that micromixing over the analyzed distance range does not commence. Analysis of the PDF in the form of the β-distribution used for calculation of the scalar field shows that it is not valid for the large-intermittence region, where not only significant discrepancies in the predicted and experimental skewness and kurtosis values exist but also their qualitatively different behavior is observed. The reason for the flow asymmetry of the recirculation zone is not yet quite clear. The studies [2, 3], where this asymmetry was first revealed, had more serious errors in mixer geometry, but their remedy did not provide a desired flow symmetry. It is very likely that the flow asymmetry near the nozzle is initiated by the jet itself. This supports the observed interaction of the jet with the recirculation zone causing the jet to deflect [4]. Being at the commencing stage calculations of this-type flow by LES permit establishing a possibility of forming the flow asymmetry in the jet mixer.

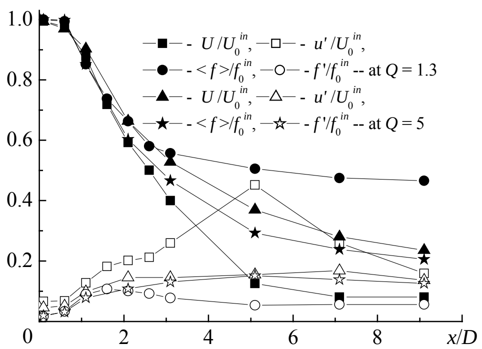

Fig. 1. Decay of the averaged velocity, averaged scalar and their rms fluctuations along the mixer axis under different regimes

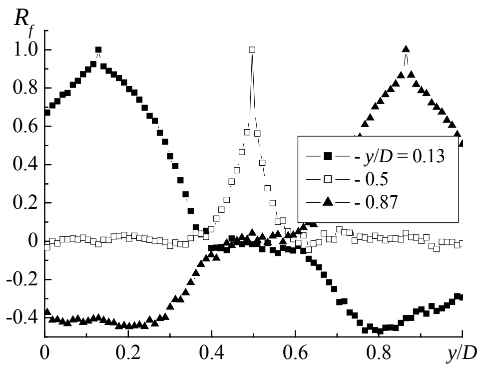

Fig. 2. Autocorrelation function at three points y/D of the mixer cross-section at $x/D = 1.6$ for $Q = 1.3$

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