Mixing of two fluids with variable viscosity

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A remarkable property of turbulence is its ability to enhance mixing of scalar contaminants, either passive (e.g., slightly heated flows), or active (e.g., resulting from multicomponent, variable-viscosity species).
The phenomenology of scalar mixing is of both fundamental and practical importance. Whereas a lot of attention is being paid to passive scalar mixing acting as a tracer (e.g., slightly heated flows), it is the active scalar (i.e. which modifies the velocity field itself) which is the most relevant for practical applications, such as combustion or geophysical flows. The active scalar of interest here results from mixing two fluids with different viscosity (the velocity field is to be modified through the viscous terms present in Navier-Stokes equations). We assess some effects of viscosity variations in incompressible, round jet of propane issuing in air. The viscosity ratio is of $\upsilon_{air} / \upsilon_{propane} = 5$, whereas the density is almost equal to one. Using analytical and experimental tools, we carry out a comparison between Constant Viscosity Flows (CVF) and Variable Viscosity Flows (VVF), at the same initial jet momentum.

It is found that viscosity variations have a non-negligible impact on mixing. VVF exhibit an acceleration of the trend towards isotropy and self-similarity. We observe more intense values of velocity fluctuations, as well as a faster trend towards isotropy in VVF than in CVF. The birth of these turbulent fluctuations most likely results from a combination of three factors:

i) Kelvin Helmoltz instabilities;
ii) Wake instabilities behind the injector lip;
iii) Interface instabilities due to viscosity jumps. i) and ii) are the same for both jets so they are not responsible for the differences between CVF/VVF.

Therefore, we conclude that interface instabilities associated with viscosity gradients are important and contribute to the enhancement of mixing.

We propose the following phenomenological scenario to explain the mixing enhancement. Viscous host fluid blobs are enticed (via the three types of instabilities) into the jet core. These viscous blobs represent obstacles which slow down the initial jet velocity and lead to the creation of radial velocity fluctuations behind these obstacles (wake instabilities). The rapid birth of radial velocity fluctuations accelerates the trend towards isotropy and self-similarity.

A deeper insight into the birth, increase and dissipation of turbulent fluctuations is provided by investigating:

i) The one-point kinetic energy budget, derived in the context of VVF. New terms, due to viscosity gradients, lead to an enhancement of the dissipation rate with respect to CVF.
ii) Two-point statistics. Scale-by-scale energy budget equations are further established, by separating the influence of the Coherent Structures (CS) on the basis of phase-averaged structure functions. We highlight a reinforcement of the cascade mechanism, associated with the presence of the CS which induce an additional strain and therefore diminish the local, turn-over time.

Bibliographic references:

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