Variable-viscosity mixing in the very near field of a round jet

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Context and collaborations:

ANR ‘Micromixing’: B. Renou, J.F. Krawczynski, G. Boutin, F. Thiesset, B. Talbot

Perspectives:

ANR ‘MUVAR’: B. Renou, A. Hadjadj, B. Patte-Rouland, A. Chinnayya, N. Taguelmimt

L. Voivenel (Oct. 2012)

F. Anselmet, M. Amielh, L. Pietri (IRPHE)
Active scalar mixing, variable-viscosity

Navier – Stokes... + \frac{\partial}{\partial x_j} \left( \mu(f) \frac{\partial u_i}{\partial x_j} \right)

\frac{df}{dt} = \frac{\partial}{\partial x_j} \left( D(f) \frac{\partial f}{\partial x_j} \right)
Active scalar mixing, variable-viscosity

Important because:

- **fundamental aspect** (most of the theory deals with homogeneous fluids, passive scalar..)

- **practical aspect**: initial phase of mixing- combustion, geophysical flows (ratio of viscosities =1000..) etc.
Active scalar mixing, variable-viscosity

Application: MACRO AND MICRO-MIXING FUEL-AIR

Both reactants (fuel and oxidizer) are generally injected through distinct channels

→ merging zone followed by a non-reacting, quasi isothermal partially premixed region

→ strong effect of turbulence (large and small scales) from the wake, the shear layer and the developed turbulence of the channels

Deep impact on the flame stabilization, structure or propagation

Two-stream coflowing jets

Fuel

Air

Near field

Far field

U(x,t)

Z(x,t)

Z_{st}

Etude en cours, couche mélange, N. Taguelmimt
Validation in an axisymmetric Jet ($Re_D=7,000$)

**Probes volumes**
- Rayleigh ($d\times L$): $80\times 200\mu m$
- Hot-wire ($d, L$): $2.5 \mu m, 400 \mu m$ ($L/d \sim 160$)
- Axial distance between volume probes = $800 \mu m$

**Detection, conditioning, filtering**
- Sampling rate $F_s = 100$ kHz
- Filtering at 50 kHz ($F_s/2$) for velocity
- Filtering at 35 kHz (Rayleigh)
- Low noise PMT: $< 0.15$ nA
- Afocal optical system, $f/D = 1.5$
- $F_c$ (Hot-Wire) $\sim 40$ kHz

**Continuous ion Laser**
- Krypton 676 nm
- 6 Watts
- Gaussian laser beam

**B. Talbot et al., Exp. Fluids 2009**
Active scalar mixing, variable-viscosity

Host fluid = 5 times more viscous than the propane

Comparison between C3H8-oxidant jet (VV) and a ‘classical’ air-ar jet (CV)

VV jet: \[ \rho'/<\rho> = 5\% \quad \mu'/<\mu> = 18\%. \]

→ Entrainment + important

→ Isotropy and self-similarity are more rapidly attained

Etude en cours, jet propane/air, L. Voivenel
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Etude en cours, jet propane/air, L. Voivenel
Active scalar mixing, variable-viscosity

- Kelvin-Helmholtz
- Wake instabilities (recirculation ?)

**Density ratio effect (macro-mixing)**

→ Lower density ratio will reduce the growth rate of mixing layer
→ Self similarity should be obtained slower

- Viscosity effects (interfacial instabilities)

**Growth rate of K.H. instabilities**

Soteriou et al. (1995)
3-rd effect of viscosity gradient: higher dissipation rate

\[ \langle \epsilon_{iso} \rangle = 15 \langle \nu \rangle \left\langle \left( \frac{\partial u}{\partial x} \right)^2 \right\rangle \]

- High local dissipation rate for propane/air/neon jet
- Strong decrease of dissipation rate
- But limitation of the experimental determination of the dissipation rate
- Towards an additional contribution to energy dissipation...
Transport equation kinetic energy ($\rho = \text{cte}, \mu \neq \text{cte}$)

Application along the jet centerline (1D):

$$
\begin{align*}
\dot{U} & \frac{\partial}{\partial Z} \left[ \frac{u_i^2}{2} \right] + \frac{\partial \dot{U}}{\partial Z} \left[ u_i^2 - \overline{v^2} \right] + 2v \frac{\partial}{\partial y} \left( \frac{u_i^2}{2} \right) \\
= & -\nu \left( \frac{\partial u_i}{\partial x_j} \right)^2 + \frac{\partial \mu}{\partial Z} \left[ \frac{\partial}{\partial Z} \left( \frac{u_i^2}{2} \right) + 2 \frac{\partial}{\partial y} \overline{uv} \right] + 3 \frac{\partial \mu'}{\partial Z} \frac{\partial}{\partial Z} \left( \frac{u_i^2}{2} \right)
\end{align*}
$$

Classical dissipation

Additional dissipation induced by viscosity gradients

$$
\langle \epsilon \rangle_{\text{visc.var.}} = \left\langle \nu \left( \frac{\partial u_i}{\partial x_j} \right)^2 \right\rangle + \langle \epsilon \rangle_{\text{corr.vitesse/visc.}} > \langle \epsilon \rangle_{\text{classique}}
$$

Question: What would be the scalar spectrum with a variable viscosity fluid?
- Obukhov-Corrsin regime?
- Batchelor regime?

\[ Sc = \frac{\mu(Y)}{\rho(Y)D} \neq 1 \]
Scalar Spectra (jet near-field region)

1D Scalar spectra along the jet axis

C3H8 into Air-Neon, Re_D = 7000

Birth of \( \sim k^{-1} \) region

\( k^{-1} \) Batchelor regime appears as Schmidt = \( \nu / D \) grows by a factor of 5.5!!

(with \( D_{C3H8-(Air+Ne)} \approx \text{cte} \))

\[ S_Z^*(\omega) = \frac{S_Z^{\text{meas}}(\omega) - S_Z^{\text{RLS}}(\omega)}{|H_{RLS}(\omega)|^2} \approx S_Z^{\text{meas}}(\omega) - S_Z^{\text{RLS}}(\omega) \]

+ Spatial filtering correction

(Wyngaard 1968)