Experimental analysis of thermal mixing at reactor conditions

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Overview

1) Description of the experimental setup
2) Remarks on data acquisition
3) Experimental boundary conditions
4) Temperatures acquired
5) Mixing inhomogeneity
6) Spectral analysis
7) Inverse heat conduction problem
1) Test section

- Inner tube
- Outer tube
- blade
- guide tube
- lower bypass inlet
- top tube
- upper bypass inlet
1) Loop, inner tube & thermocouple discs
2) Thermocouple discs & rod motion

- **Right thermocouple disc**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc diameter</td>
<td>11.90 mm</td>
</tr>
<tr>
<td>Disc max. height</td>
<td>4.70 mm</td>
</tr>
<tr>
<td>Hole max. diameter</td>
<td>1.02 mm</td>
</tr>
<tr>
<td>Distance from holes to Q</td>
<td>3.00 mm</td>
</tr>
<tr>
<td>Hole depth</td>
<td>from 0.35 mm to thru</td>
</tr>
</tbody>
</table>
3) Experimental boundary conditions at sampling rate = 1000 Hz

<table>
<thead>
<tr>
<th>Case number</th>
<th>$\dot{m}_H$ (kg/s)</th>
<th>$\dot{m}_C$ (kg/s)</th>
<th>$T_H$ (K)</th>
<th>$T_C$ (K)</th>
<th>$p$ (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8</td>
<td>0.07</td>
<td>549</td>
<td>333</td>
<td>72</td>
</tr>
<tr>
<td>2</td>
<td>0.6</td>
<td>0.07</td>
<td>549</td>
<td>333</td>
<td>72</td>
</tr>
<tr>
<td>3</td>
<td>0.6</td>
<td>0.14</td>
<td>549</td>
<td>423</td>
<td>72</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>0.08</td>
<td>549</td>
<td>348</td>
<td>72</td>
</tr>
</tbody>
</table>

Not treated here

Treated here
4) Temps acquired in Case 1

Homogeneous mixing

- H2 at 0.72 m and 45°
- H2 at 0.70 m and 45°
- H2 at 0.67 m and 45°
- H2 at 0.65 m and 45°

Incipient mixing

- H2 at 0.63 m and 45°
5) Normalized temperatures in Case 1

\[ T_{f,d}^* = \frac{T_{f,d} - \tilde{T}_C}{\tilde{T}_H - \tilde{T}_C}, \quad \zeta = \frac{z_H - z}{D_{hyd}} \]

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<tr>
<th>Case</th>
<th>( \dot{m}_H ) (kg/s)</th>
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5) Mixing inhomogeneity in Case 1

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6) Temperatures in Case 1 at 45°

<table>
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<tr>
<th>Case</th>
<th>$\dot{m}_H$ (kg/s)</th>
<th>$\dot{m}_C$ (kg/s)</th>
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<th>$T_C$ (K)</th>
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</tbody>
</table>

at 0.67 m and 45°

at 0.65 m and 45°

at 0.63 m and 45°
6) Spectral analysis in Case 1 at $45^\circ$
6) Peaks in Case 1

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<tr>
<th>Case</th>
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- **$\Delta g$ (•) vs. $\omega$ (Hz)**
  - highest peaks for $l = 1$
  - second highest peaks for $l = 1$
Conclusions

- A number of data sets were acquired to validate CFD models
- No incipient mixing below 0.60 m
- At high mixing inhomogeneity, \( \max(T) < \) adiabatic mixing temperature
- At high mixing inhomogeneity, 0.03 – 0.10 Hz
- At high mixing inhomogeneity, higher spectral peaks → mixing estimator along \( z \) seems fine
- Repeatability OK
- Squeezing all temps at the same position in one scalar OK
- The region with low-frequency, high-amplitude fluctuations moves upwards with decreasing hot mass flow rates
- Thermal stratification amplifies mixing estimators and contracts the range of normalized temperatures at the level where this range is highest by smearing it over several axial levels, at least when the hot mass flow rates are low
- Asymmetry between 180º and 360º, at least when the hot mass flow rates are high
- EMD seems fine
- The IMFs responsible for the highest spectral peaks often correspond to the largest time scales
7) Inverse heat conduction problem

- Optimization problem
- 3D domain
- Non-simply connected domain
- Transient case

Usual approaches:
1. Solve direct, adjoint, and sensitivity sub-problems
2. Overspecify boundary conditions on parts of the boundary and smooth temperatures at the unknown boundaries
3. Use Trefftz functions

So far, only approach 2 has proven mildly successful, for steady-state problems
7) Inverse heat conduction problem
Next steps

- Improve uncertainty with URANS to better assess the thermocouple mounting error (50% done?)
- CEEMD
- Thermal stresses from upgraded LES
- Methodologies to estimate risks of fatigue crack formation
Publications


Thank you for your attention!

Questions?

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