Experimental and numerical studies of the influence of diluent on characteristic micro-scale combustion flame behaviour

Hugo Chouraqui, Christian Chauveau, Philippe Dagaut, Guillaume Dayma, Fabien Halter

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1. Goal of the study

- Growing need to improve knowledge in the field of small-scale combustion and take advantage of high energy density of fuel [1] in different applications such as portable power device [2], micro-satellite thrusters [3], heat sources [4].
- Previous studies have been done with fuel/air mixtures. Combustion of a CH<sub>4</sub>/O<sub>2</sub> mixture with different diluents can improve the understanding of flame behaviour in micro-scale reactor by changing physical properties of the environment. Hence, be able to point out physico-chemical properties that play an important role in micro-scale combustion.

2. Experimental set-up

- Cylindrical quartz tube heated by 3 hydrogen/oxygen blowtorches.
- The temperature profile on the outer side is measured by a infrared camera A655sc.
- A spectroscopy EMCCD camera ProEM 1600 with a CH<sub>4</sub> band-pass filter (208PPF1_430) is used to detect the flame positions.
- CH<sub>4</sub>/diluent mixture is supplied in a 1.85 mm internal diameter reactor. (Quenching distance of CH<sub>4</sub>/air is 2.50 mm)

3. Different flame behaviour

a) FREI (Flame with Repetitive Extinction and Ignition): the ignition occurs downstream in high temperature region and extinction occurs upstream in low temperature region.

b) Stable flame: flames with no relative motion with the reactor wall.

4. Experimental and numerical results

<table>
<thead>
<tr>
<th>Diluent</th>
<th>O&lt;sub&gt;2&lt;/sub&gt;</th>
<th>He</th>
<th>N&lt;sub&gt;2&lt;/sub&gt;</th>
<th>He/N&lt;sub&gt;2&lt;/sub&gt;/O&lt;sub&gt;2&lt;/sub&gt;</th>
<th>He/air stoichiometric mixture with a flow velocity of 0.4 m/s, 0.415 m/s, 0.7 to 1.0 m/s [6]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>20%</td>
<td>0%</td>
<td>80%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>He/air</td>
<td>21.18</td>
<td>39.20</td>
<td>83.62</td>
<td>78.32%</td>
<td></td>
</tr>
<tr>
<td>He/O&lt;sub&gt;2&lt;/sub&gt;</td>
<td>21.68</td>
<td>78.32</td>
<td>0%</td>
<td>80%</td>
<td></td>
</tr>
</tbody>
</table>

Compositions of diluents used in this study in molar fraction

Laminar burning velocity and adiabatic flame temperature of a stoichiometric mixture CH<sub>4</sub>/diluent

4.1. FREI

- For a given fuel/oxydant mixture: when the flow velocity increases → frequency increases
- For a given flow velocity: when the flame propagation speed of a mixture A is bigger than a mixture B → t<sub>ext</sub> in A is smaller than in B

4.2. Stable flame

Solution methods and solvers
- Steady state simulation
- The Stiff Chemistry Solver of ANSYS Fluent is used to solve the reactive flow
- PISO method for velocity-pressure coupling is used to solve the discretized form of the Navier-Stokes system
- A second order upwind spatial discretization is used and a least squares cell-based method for the evaluation of gradients

Boundary conditions:
- Experimental external wall temperature is averaged and used as boundary condition
- A velocity inlet boundary condition is applied on the left part of the geometry, and a pressure outlet boundary condition (1 atm) on the right part

Models:
- A laminar viscous model
- The effect of enthalpy transport due to species diffusion in the energy equation
- Ideal gas
- Chemical, transport and thermodynamic properties are computed with the GRI-Mech 3.0 scheme

Stable flame position defined at the external wall temperature as a function of the mixture flow velocity

Wall temperature and flame front visualisation

- For a given fuel/oxydant mixture: flow velocity increases → the flame goes toward colder wall reactor region
- For a given flow velocity: when the adiabatic flame temperature of a mixture A is bigger than a mixture B → the front flame is located to colder wall reactor region.

5. Conclusions

- All characteristic flame behaviours are conserved with different diluents studied
- The increase in He molar fraction in diluent → a. FREI velocity domains increases
b. Extinction is located to colder wall region
c. Stable flame is located to colder wall region

- Flame/wall thermal interaction clearly identified experimentally with stable flames but not numerically

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